Effect of Sight Distance on the Safety Of Unsignalized Intersections

by

Khaled Abdulaziz Ahmad Al-Abdulgader

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
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بسم الله الرحمن الرحيم

Dedicated to
My Parents

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الخلاصة

تعانى التقاطعات فى المملكة العربية السعودية من حوادث كثيرة لذلك فان فهم أسباب هذه الحوادث قد يقود الى نتائج تساعد على وضع استراتيجية تحسين أفضل .

ان الهدف الاساسى من هذه الدراسة هو بحث تأثير البعد النظرى على السلامة فى التقاطعات باستخدام طريقة التضارب المرورى لأنة لايوجد حاليا احصائيات موثوقة عن الحوادث .

ولتحقيق هذا الهدف تم جمع المعلومات المطلوبة من واحد وعشرين تقاطعا فى المنطقة الشرقية بالمملكة العربية السعودية . وباستخدام هذه المعلومات تم معرفة تأثير البعد النظرى فى التقاطعات على السلامة وهى مبينة ضمن نتائج هذا البحث والتى تشمل ايضا التوصيات المناسبة لتحسين وتطوير السلامة فى التقاطعات .

ABSTRACT

Fifty percent of accidents occur at intersections. Therefore understanding the problems at intersections may lead to better improvement strategies.

The main goal of this study was to investigate the effect of sight distance on the safety of unsignalized intersections using traffic conflicts. Traffic conflicts were employed because reliable accident information is not available at this time.

Conflict studies have been carried out at twenty-one intersections in the Eastern Province. Using this data the effect of sight distance have been analyzed.

The analysis was done using Multiple Regression Analysis, Analysis of Variance and Covariance, and Multiple Classification Analysis. Uncontrolled and stop controlled approaches have been analyzed separately.

Finally conclusions of the study and recommendations for the improvement of safety at unsignalized intersections were reported.

Chapter 1

INTRODUCTION

Around 50 percent of accidents occur at intersections (1,2). Therefore understanding the problems at intersections may lead to better strategies for the improvement of safety on the roads.

One of the problems that is thought to be a serious one is the available sight distance. Sight distance is one of the important elements that affects safety and operation.

The effect of sight distance was investigated by some industrialized countries using traffic accidents (3,4,5). However, these studies did not predict the effect for different intersection types with different types of control.

Using detailed accident analysis at intersections the type of relationship can be identified. But currently such reliable statistics are not available in Saudi Arabia. Therefore this study used traffic conflict technique to study the effect of sight distance on the safety of unsignalized intersections.

A traffic conflict is defined as :

> "... a traffic event involving two or more road users, in which one user performs some atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive maneuver is undertaken"(p.18,6).

Traffic Conflict Technique (TCT), was first introduced in

1967 by the General Motor Corporation (7), and evaluated by the US Federal Highway Administration in 1969 (8), and in many other countries, like United Kingdom, Canada, Sweeden, France, Australia, and Germany,(9,10,11,12,13,14,15). Thus the technique has generated a great deal of international interest, with many countries funding extensive research into various aspects of TCT.

Traffic Conflict Technique measures the potential and operational deficiencies of a highway location without having to wait for a suitable accident history to evolve.

The international research involving or using traffic conflict technique has concentrated on the following areas of investigations:

1) Relationship between a specific type of conflict and a specific type of accident;
2) Accident prediction;
3) The identification of hazardous locations;
4) Hazard diagnosis; and
5) Traffic improvement evaluation, i.e. as a cost-effectiveness technique.

TCT is applied for different purposes at various locations:

1) Intersections;
2) Construction zones;
3) Acceleration lanes;

4) Lane drops;

5) By-passes; and

6) Ramps.

Chapter 2

PROBLEM STATEMENT

The need for the research and the objectives of the research are given in the following sections:

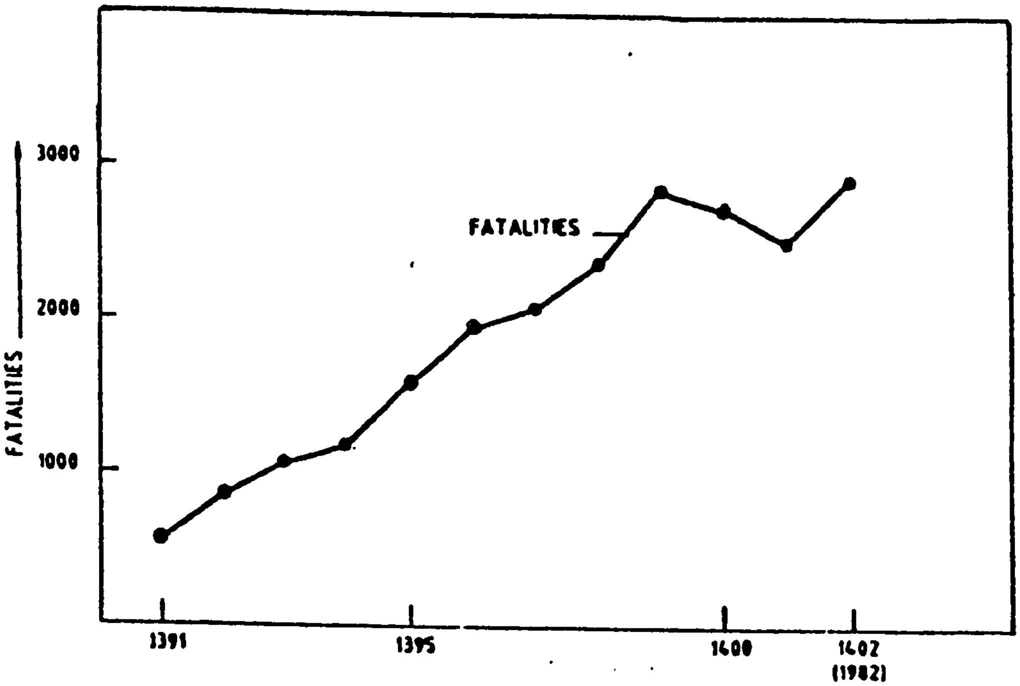
2.1 Problem definition

Almost fifty percent of the accidents occur at intersections(1,2). Highway accidents are considered to be a major cause of death in all countries as well as in Saudi Arabia. Figure 1 shows the tremendous increase of accident fatalities and injuries in Saudi Arabia. Also, the rate of accidents in Saudi Arabia is approximately 4 to 5 times greater than the industrialized countries(16).

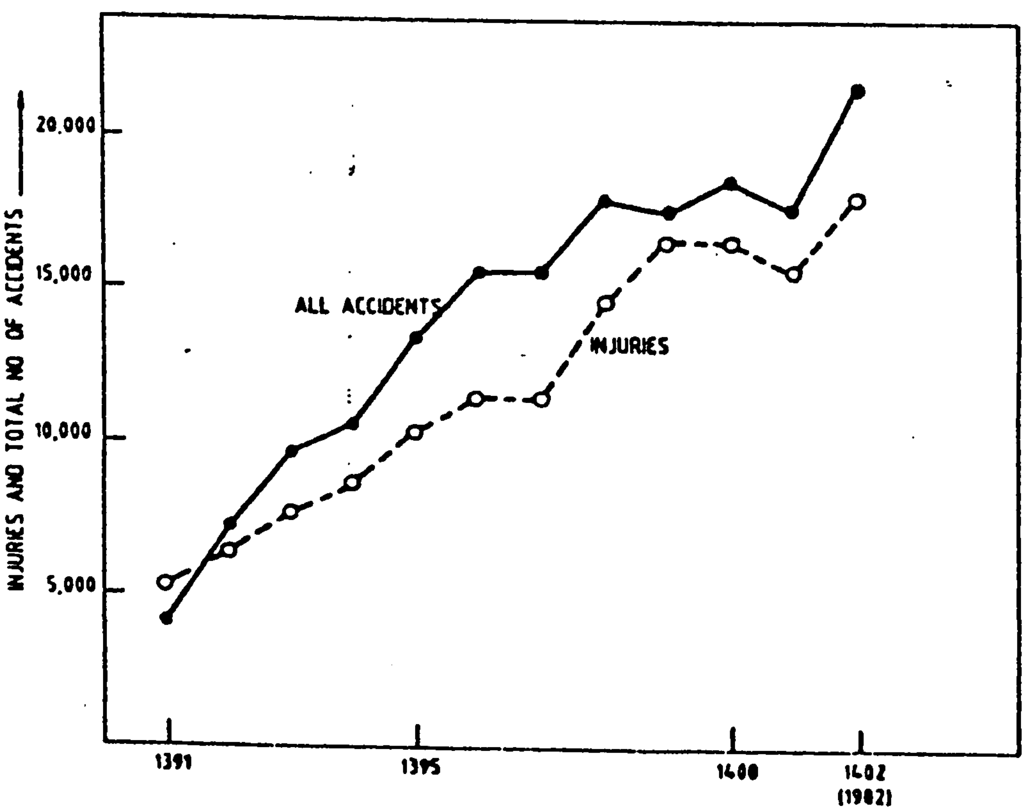
One of the main recommendations of a major study(16) which investigated highway safety problems in Saudi Arabia was that engineering improvement in highways were to be given a high priority in the safety programs. Sight distance is one of the important elements that affect safety and operation. Insufficient sight distance is believed to be one of the main causes of accidents. Therefore, this study will investigate the effect of sight distance on the safety of unsignalized intersections.

2.2 Study objectives

The objectives of this study are to:



(a) FATALITIES



(b) INJURIES AND ALL ACCIDENTS

Figure 1. INCREASE IN TRAFFIC ACCIDENTS.

(Source ::Reference(16), p.4)

1. Investigate the effect of sight distance on the safety, which is measured by the number of conflicts, of unsignalized intersections.
2. Come up with a factor for sight distance to be used in the prediction of accident potential at unsignalized intersections.
3. Recommend strategies for improving some of the geometrical and operational problems based upon findings of the research.

Chapter 3

LITERATURE REVIEW

3.1 Effect of Sight Distance on Intersection Safety

The concept of sight distance is one of the most important criteria in highway design. It affects safety, vehicle operations, and has a major impact on construction costs. Therefore, it is important that the elements that determine sight distance be as accurate as possible.

An evaluation of Federal Highway Safety Program Projects (3) indicated that, out of a total of 34 different improvement types, the improvement of sight distance at intersections was the most cost effective. Improvement benefits exceeded costs by a factor of five.

A before and after study in Concord, California (4), illustrated that the accident rate at most intersections generally decrease if sight obstructions are removed. In this study, sight distances at five intersections were improved. Total accidents at these intersections dropped from 39 in the year before to 13 in the year after obstruction removal, a 67 percent reduction as shown in Table 1. In the same study, other intersections were improved by means of signal installation or modification, delination striping, improved pavement markings, and increased police enforcement. It was found that sight distance improvement

Table 1- Accident Data Before and After Improvement

Type of improvement	Locations	No.of accidents 1 year Before	1 year After	Percent Reduction
Signal installation or modification	27	366	285	22
Deliaetion stripping	5	28	22	21
Pavement markings	7	34	22	35
Adjust signal timing and increased enforcement	6	78	41	48
Improve sight distance	5	39	13	67
Flashing beacons	3	22	16	27

Source: Reference (4), P.76

resulted in the greatest reduction.

The Stanford study (5) showed that intersectional accident potential could be reduced 10 to 25 percent if the right angle sight distance, as seen by a driver from a main road vehicle 50 feet away from the intersection, could be increased from a point 20 feet from the intersection to 50 feet away. (Figure 2 illustrate the 50-foot sight distance triangle.)

A 50-foot sight distance triangle was also considered optimum by 154 government officials in a study of sight distance obstructions on private property (17). The surveyed officials felt that a 30-foot sight distance triangle was adequate when the intersection was regulated by traffic control devices.

A study by Michigan Department of Highways and Transport (18) found that intersections with limited sight distance had significantly higher rates of accidents and severity than those with no sight distance limitations.

Another study of intersection accidents in rural Virginia municipalities compared the effect of poor sight distance and severe grade on accident occurrence (19). The results are shown in Table 2. The accident rate at intersections with poor sight distance was higher than intersections with severe grades. Apparently drivers were aware of poor physical conditions and exercised more than average caution at those locations. While at the sight restricted intersections, the high rate of accidents was due to the large number of angle collisions, a result of the inability of

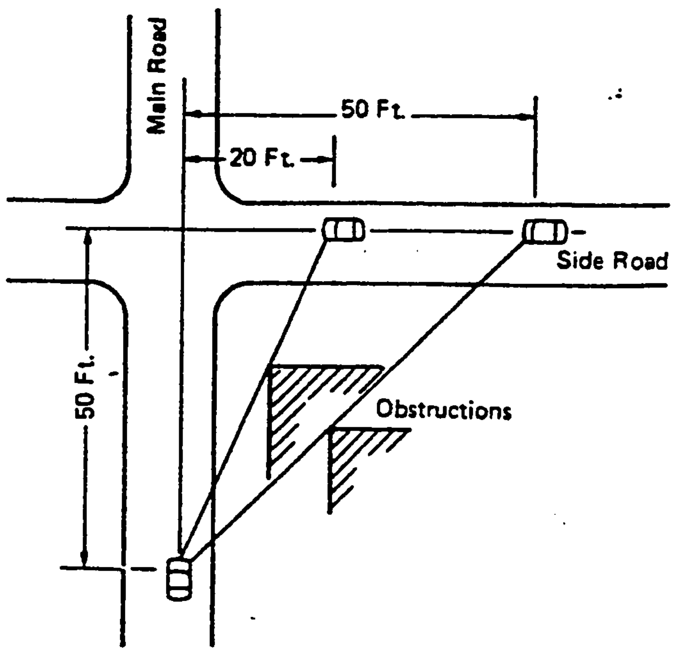


Figure 2. Typical Sight Distance Triangles

(Source : Reference (5)).

Table 2- Variation in Accident Type and Rate at Physically Deficient Intersections

Intersection Condition	Rear End	Angle	Side-swipe	Other	Accident Rate*
Severe Grade	39	38	9	14	0.97
Poor Sight Distance	20	56	9	15	1.33

* Accidents per million entering vehicles
Source: Reference (19).

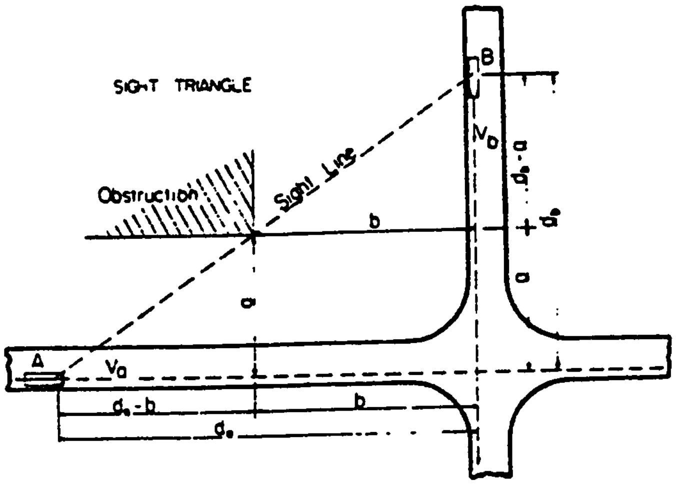
drivers to properly view vehicles approaching on cross streets.

3.2 Sight Distance Design Procedure

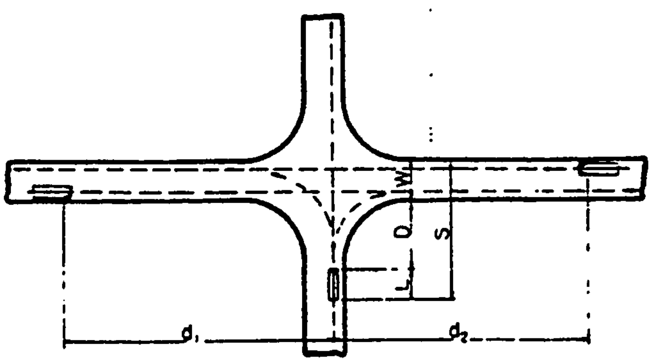
Intersection sight distance is the minimum distance required to respond appropriately to approaching traffic. At intersections, sight triangles are used to define the required sight distance. The legs of the triangle are formed along the intersecting paths of the conflicting vehicles, see Figure 3. The length of the triangle legs can be determined based on the control of the intersection and the approach speed. The criteria for sight distance for each control is explained in detail in AASHTO (20). The sight distance criteria for uncontrolled and stop controlled intersections are summarized in the following paragraphs:

Case I - Uncontrolled Intersections

At uncontrolled intersections, vehicles are assumed to adjust speed. The operator of a vehicle approaching an intersection must be able to perceive a hazard in sufficient time to alter the vehicle's speed as necessary before reaching the intersection. The amount of time necessary for altering the vehicle's speed is the driver's perception and reaction time, which can be assumed to be 2.0 seconds. One more second is added to allow for actuating brakes or accelerating. So ,the average distances traveled by a vehicle in 3.0 seconds are the following:



CASE I- NO CONTROL



CASE II- STOP CONTROL ON MINOR ROAD

Figure 3. Sight distance at intersections.

Source: Reference (20), P.776

Speed(Mph)	Distance(Ft)
10	45
15	70
20	90
25	110
30	130
35	155
40	180
50	220
60	260
70	310

The sight triangle is determined by the above minimum distances along the road. For example, if approaches A and B (Figure 3, case I) have design speeds of 40 and 30 Mph respectively, the sight triangle legs d_a and d_b should be 180 and 130 ft respectively. These, or greater distances, will permit a vehicle on either road to change speed before reaching the intersection.

Intersections with sight triangles approximately equal to those indicated are not necessarily safe. There is potential confusion to operators with the possibility of a driver on one highway being confronted with a succession of vehicles on the intersecting highway when the time and distance are sufficient only to avoid one vehicle. Even where only one vehicle on each of the adjacent legs approaches an intersection, both vehicles may begin to slow down and reach the intersection at the same time.

A more preferred design for uncontrolled intersections takes into account perception-reaction time and stopping before reaching the intersection. This criteria is called the stopping sight distance criteria (SSD). It is the minimum distance required to safely react and stop in response to an unsafe condition.

The design standards for minimum stopping sight distance is expressed as a function of the design speed of the roadway (see Table 3). The distance required for stopping also depends on the friction between the wheels and the pavement. As the speed increases, the coefficient of friction decreases. The coefficient of friction also decreases when the pavement becomes wet. Therefore the SSD values in Table 3 are for wet pavement.

Case II - Stop controlled Intersections

When stop control is used on a minor road, it is necessary to provide for the driver of the stopped vehicle to see along the major highway a sufficient distance for him to cross the highway without interfering with the oncoming vehicles. There are three basic maneuvers that occur at the average intersection. These maneuvers are:

1. To cross the intersecting roadway;
2. To turn left into the crossing roadway; and
3. To turn right into the crossing roadway.

These three conditions are shown by the cases A, B, and C, respectively, on Figure 4.

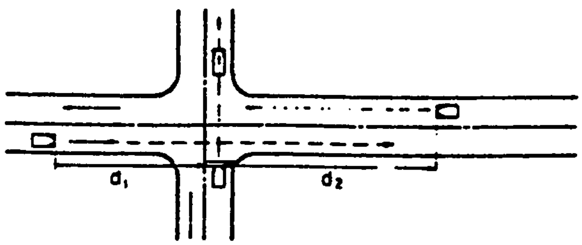
The stop condition criterion that will be presented is applicable to two-lane, two-directional roadways through multilane divided highways. Where the principal roadway is either undi-

Table 3- Stopping Sight Distance (Wet Pavement)

Design Speed (mph)	Brake Reaction		Friction coefficient	Braking distance (ft)	SSD rounded (ft)
	Time(sec)	Dist(ft)			
20	2.5	73.3	0.40	33.3	125
25	2.5	91.7	0.38	55.8	150
30	2.5	110.0	0.35	85.7	200
35	2.5	128.3	0.34	120.1	250
40	2.5	146.7	0.32	166.7	325
45	2.5	165.0	0.31	217.7	400
50	2.5	183.3	0.30	277.8	475
55	2.5	201.7	0.30	336.1	550
60	2.5	220.0	0.29	413.8	650
65	2.5	238.3	0.29	485.6	725
70	2.5	256.7	0.28	583.3	850

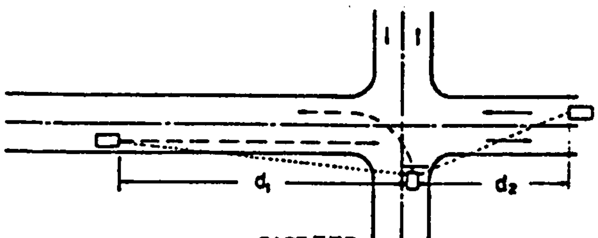
Source: Reference (20), P.138

CASE II STOP CONTROL



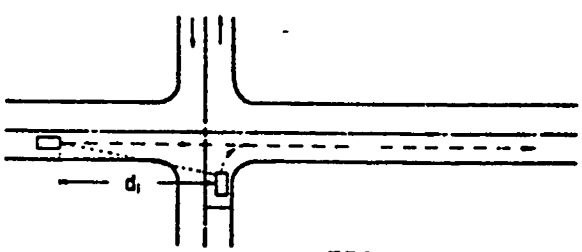
CASE IIA

STOPPED VEHICLE CROSSING A MAJOR HIGHWAY



CASE IIB

STOPPED VEHICLE TURING LEFT ONTO TWO LANE MAJOR HIGHWAY



CASE IIC

STOPPED VEHICLE TURNING RIGHT ONTO TWO LANE MAJOR HIGHWAY OR RIGHT TURN ON A RED SIGNAL

* d = Sight Distance

Figure 4 . Intersection sight distance at at-grade intersections.

(Source : Reference (20), p.785)

vided or divided with a narrow median, the departure maneuvers are treated as a single operation. Where the major roadway is divided and has a wide median, that can store the design vehicle safely, the departure maneuvers are considered as two operations. The first operation concerns the traffic approaching from the left for all three maneuvers; that is, crossing the entire roadway, crossing a part of the roadway and turning left into the cross road or turning right into the cross road. The second operation concerns traffic from the right for the first two maneuvers; that is, continuing to cross the major roadway or turning left and merging with traffic from the right.

Case IIA - Crossing Maneuver

The sight distance for a crossing maneuver is based on the time it takes for the stopped vehicle to clear the intersection and the distance that a vehicle will travel along the major road at its design speed in that amount of time. See Figure 4, case IIA.

Figure 5 shows the sight distance d necessary for safe crossing from a stopped position with pavements of 12-ft lanes at nearly right-angle intersections.

In testing whether a sight distance along a major highway is adequate at an intersection as given in Figure 5, the distance should be measured from a height of eye of 3.5 ft to the top of an object, 4.25 ft above the pavement.

When using the curves on Figure 5 for two-lane and four-

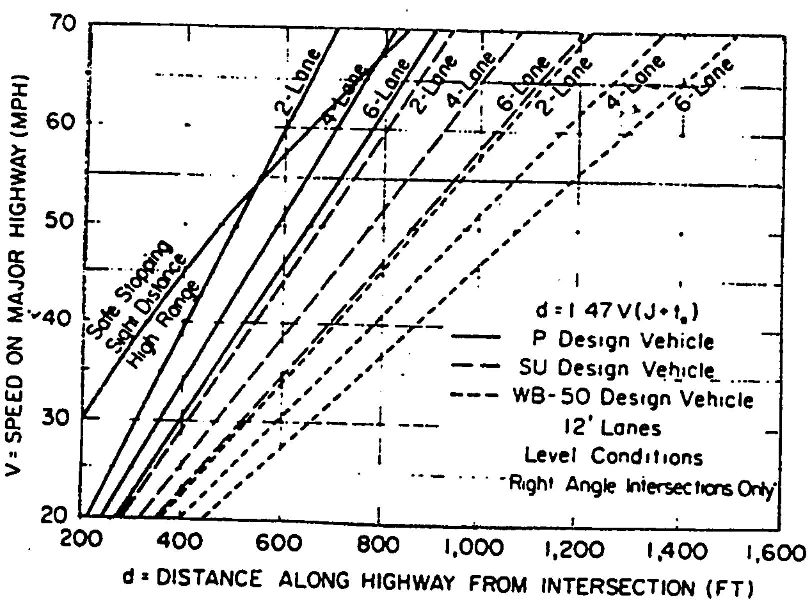


Figure 5 . Sight distance at intersections (case IIA, required sight distance along a major highway).

(Source: Reference (20), P.791).

lane crossings for a P design vehicle, the d dimension for design speeds over 55 mph should not be less than the safe stopping sight distance, high range.

Case IIB - Turning left into a cross road

Figure 4, case IIB, illustrates a vehicle entering a cross road from a stopped position by clearing vehicles approaching from the left and then by turning left and entering the traffic stream from the right.

Figure 6 contains data for a P design vehicle turning left into a cross road. Curve B-1 indicates the sight distances required for the turning maneuver with respect to vehicles approaching on the left. Curve B-2b indicates the sight distance required to perform the left-turn maneuver and to accelerate to the average running speed of the major road before being overtaken by vehicles that are approaching the intersection from the right and reducing their speed from the design speed to the average running speed. Curve B-2a indicates the sight distance required to perform the left-turn maneuver and to accelerate to the design speed of the major road before being overtaken by vehicles that are approaching from the right and maintaining design speed throughout the turning maneuvers.

Case IIC - Turning Right Into a Cross Road

Figure 4, case IIC, indicates a vehicle departing from a

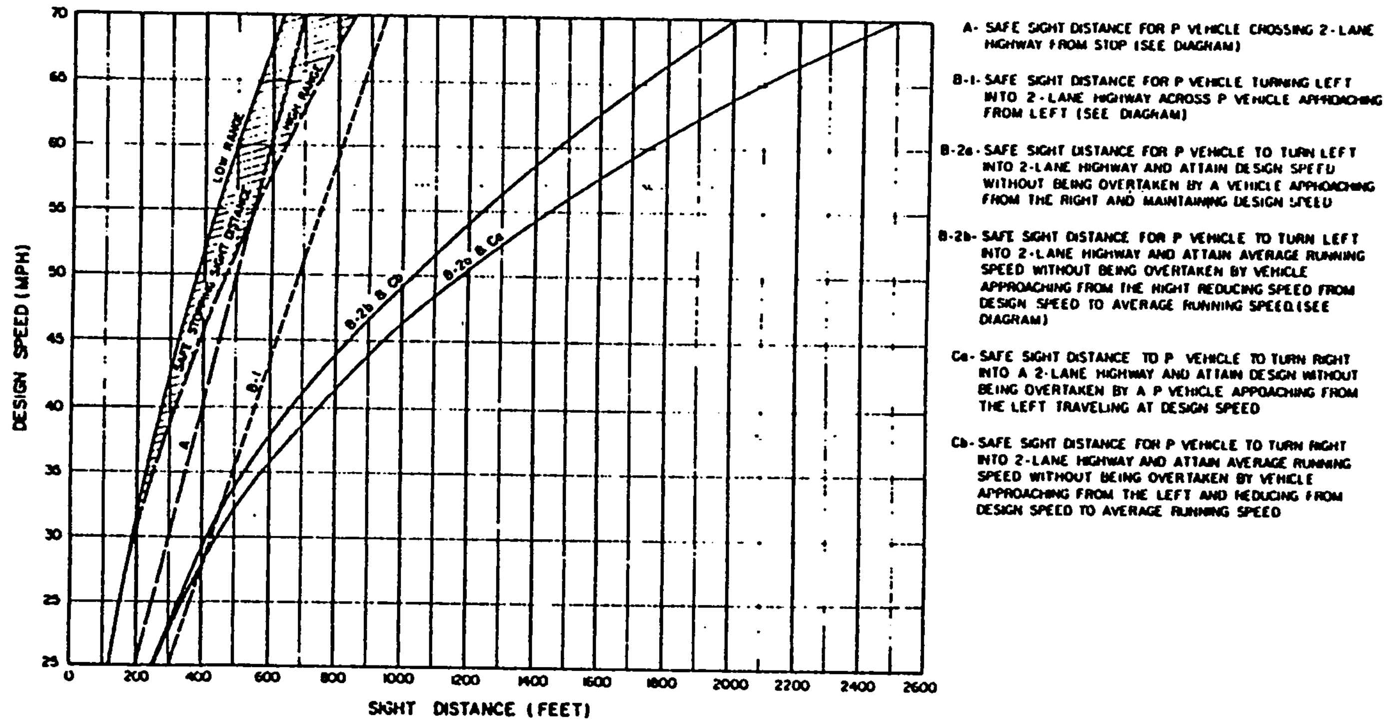


Figure 6 ·. Intersection sight distance at at-grade intersection (case IIIB and case IIIC).

(Source: Reference (20, P.792).

stopped position, turning right and merging with traffic from the left.

Figure 6 contains data for a P design vehicle turning right into a cross road. Curve Cb is the safe stopping distance for a passenger vehicle to turn right into a major roadway and accelerate to average running speed without being overtaken by vehicles approaching from the left and reducing their speed from design speed to average running speed. Curve Ca is the safe stopping sight distance for a P design vehicle to turn right into a two-lane major roadway and attain design speed before being overtaken by vehicles approaching from the left and maintaining design speed throughout the turning maneuver.

3.3 Relationship between Traffic Conflicts and Accidents

Perhaps the most important potential application of the TCT is in identifying safety deficiencies. Conventionally, safety is measured in terms of accidents and accident rates -- the ultimate measure. Unfortunately, accidents are so rare, statistically, that one must often wait for years, and for many accidents to happen, before enough data are available to enable rational decisions. If a surrogate measure such as traffic conflicts could be used, decisions might be made much more quickly.

It is generally agreed that conflicts and accidents are related some how. In certain cases, statistical relations were found to be significant (2), but not in others (14). The relationship between injury accidents and serious conflicts was proved to be statistically significant (12). A study of 24 intersections having a variety of geometric and traffic control conditions showed that 15 minutes conflict counts of cross-traffic, same direction (rear end), and opposing left turn, are related to accidents (6).

A study at 46 urban intersections located in four cities in the greater Kansas City metropolitan area (21) indicated that traffic conflicts of certain types are surrogates for accidents in that they produce estimates of average accident rates nearly as accurate, and just as precise, as those produced from historical accident data. Therefore, if there are insufficient data to produce a relaible analysis, a conflicts study should be very helpful.

Chapter 4

METHODOLOGY

4.1 Experimental Design

This study considered only unsignalized intersections because sight distance for signalized intersections is not as important as for unsignalized ones. The types of control included in this study are: no control and stop (or red flashing) control.

Intersection type also affects safety. But for different intersection types, sight distance has a different effect. Therefore, cross intersections and T/Y intersections were included in this study.

A full factorial design was considered as shown in Table 4. A minimum of 4 approaches were obtained for each cell in this table in order to make the data reliable. These four approaches were randomly selected from a pool of approaches with the desired characteristics. The random selection was accomplished by numbering all the approaches that fall into each cell. Each cell had different numbers. Then, by writing the numbers on small pieces of paper, four approaches were selected by picking up four pieces of paper at random.

4.2 Study Variables and Research Hypothesis

The dependent variables that were used in this study are

Table 4- Full Factorial Design of the Experiment

Sight Distance	No control		Stop Control	
	T/Y	Cross	T/Y	Cross
Sufficient	4	4	4	4
insufficient	4	4	4	4

traffic conflicts (the definition and types of traffic conflicts are explained in Appendix A). As discussed earlier, reliable accident data are not available, so traffic conflict technique was suggested to be used to evaluate safety at intersections.

The dependent variables were formed by grouping conflicts into the following two categories:

1. Rear End Conflicts. This includes the following types of conflicts: left turn same direction, right turn same direction, slow vehicle through direction, and lane change.
2. Right Angle Conflicts. This includes the following types of conflicts: opposing left turn, left turn from right, right turn from right, cross traffic from left, cross traffic from right, and left turn from left.

A variety of independent variables that are believed to have influence on conflicts were used. These variables include:

- available sight distance (which is measured as a proportion of the standards defined by AASHTO, such as perception reaction sight distance (PRSD), safe stopping sight distance (SSSD), crossing sight distance (CRSD), and turning sight distance (TUSD));
- approach volume for one direction only (vehicles per 40 minutes);
- crossing volume for both directions of the crossing street (vehicles per 40 minutes);

- total volume entering the intersection (vehicles per 40 minutes);
- total left and right turns in the intersection (vehicles per 40 minutes);
- average speed of each approach (KPH);
- standard deviation of speed;
- skewness index of speed (which measures the skewness from normal distribution);
- type of intersection (T/Y or cross intersection);
- type of control (stop control or no control);
- existence of lane marking (exists or does not exist);
- existence of left turn pocket (exists or does not exist);
- existence of pedestrian crossing (exists or does not exist);
- existence of median (exists or does not exist);
- number of lanes of one direction of the approach (1,2, or 3 lanes);
- approach width for one direction only (Meters); and
- lane width for one direction only (Meters);

Table 5 shows the *a priori* hypotheses for this study. In this table (+), (-), and "No" indicate the expected relationships. For example, it is expected that right angled conflicts at uncontrolled approaches decrease as PRSD increase. While at stop controlled approaches, there might be no relation between conflicts and PRSD. Confilcts are also expected to increase as approach vol-

Table 5 : **Research Hypothesis**

VARIABLES	*Uncontrolled*		*Stop Controlled*	
	Rear End Conflicts	Right Angled Conflicts	Rear End Conflicts	Right Angled Conflicts
PRSD	(-)	(-)	No	No
SSSD	(-)	(-)	No	No
CRSD	No	No	(-)	(-)
TUSD	No	No	(-)	(-)
Approach Volume	(+)	(+)	(+)	(+)
Crossing Volume	(+)	(+)	(+)	(+)
Total Volume	(+)	(+)	(+)	(+)
Left and Right Turns in the Intersection	(+)	(+)	(+)	(+)
Average Speed	(+)	(+)	(+)	(+)
Standard deviation	(+)	(+)	(+)	(+)
Skewness Index	(+)	(+)	(+)	(+)
Approach Width	(-)	No	(-)	No
Lane Width	(-)	No	(-)	No
Existence of Lane Marking	(-)	(-)	(-)	(-)
Existence of Median	No	(-)	No	(-)
Existence of Pedestrain Cross	(+)	No	(+)	No
Existence of Left Turn Pocket	(-)	No	(-)	No
No. of Lanes	(-)	No	(-)	No
Intersection Type	(+)	(+)	(+)	(+)

Note : (+), (-), and "No" indicates the expected relationships ume increase as indicated by the positive relationship in the table.

4.3 Data Collection

The intersections were randomly selected from the pilot study area (i.e. Dammam, Khobar, Aghrabia, and Thoqbah). A short description of the selected intersections is presented in Appendix B.

The data collected for each leg of the intersections were:

1. Traffic conflicts;
2. Speed measurements;
3. Traffic volume counts; and
4. Detailed drawing of the intersection including the distances to the nearest obstructions on both sides of each approach to allow for calculating the available sight distance.

The data were collected during the working days of the week, i.e. Saturday through Wednesday. One person was assigned at each leg of the intersection. Each person was responsible for counting the approach volume and traffic conflicts of the same approach. Four rounds were needed with 20 minutes each.

Two persons were needed to measure the speed. The two persons measured the speed of one direction, i.e. North-South road, in the first and third rounds. The same two persons measured the speed of the other direction, i.e. East-West road, in the second and fourth rounds. So, in total, 6 persons were needed for cross intersections, and 5 persons for T/Y intersections.

The equipment used were: Tallyboards for volume counting, Radar for speed measurement, and a Meter for measuring the distances.

The needed time was 80 minutes plus the recording and filling time which constituted approximately of 20 minutes more. So, the total time was approximately 100 minutes. The first two observations were combined together, making it 40 minutes observation. The same thing was done to the third and fourth observations.

4.4 Procedure Used for Calculating the Available Sight Distance

Since sight distance criteria depends on the design speed of each approach of the intersection, the 95 percentile of speed was used as the design speed. This assumption was necessary to calculate the available sight distance using any of the criteria explained by AASHTO. For example, if the 95 percentile of speed of approach A in Figure 3, case I, is 40 mph and that of B is 30 mph, then the required sight triangle legs, using perception reaction sight distance criteria (PRSD), should be 180 ft (55 m) and 130 ft (40 m) for each approach respectively. But any obstruction within the triangle will not permit the attainment of the full sight distance. The available sight distance for drivers on approach A, when they are 55 m to the intersection point, is how much distance they can see from approach B divided by the required distance, which is 40 m. This can be calculated by the following equation:

$$ASD = \left(\frac{a\, d_a}{d_a - b}\right) \left(\frac{1}{d_b}\right)$$

where

ASD = Available Sight Distance

a = distance betweeen the obstruction and the path of drivers on approach A

b = distance betweeen the obstruction and the path of drivers on approach B

d_a = required distance on Approach A

d_b = required distance on Approach B

The first term in this equation calculates the distance that drivers on approach A can see from approach B, which is Y in Figure 7. The second term is the reciprocal of the required distance on approach B. The following example explains the procedure used for calculating the available sight distance for uncontrolled and stop controlled approaches.

Example

Given :

Design speed of approach A = 40 MPh

Design speed of approach B = 30 MPh

Lane width = 12 ft

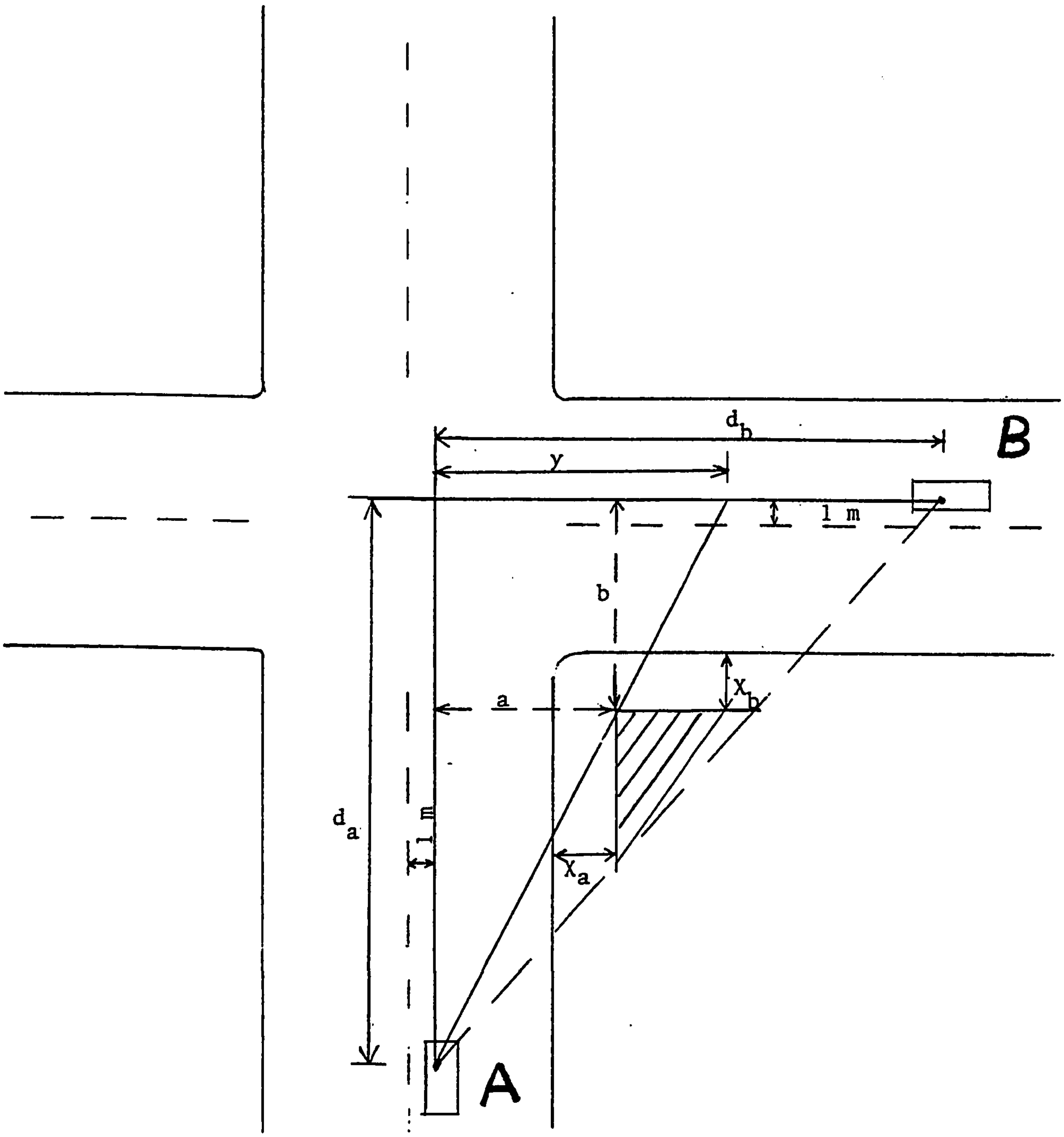


Figure 7: Sight Distance at Intersections

Parking lane widths = 10 ft

$X_a = X_b$ = 10 ft (see Figure 7)

Solution 1:

If approaches A and B are uncontrolled, then the perception reaction sight distance criteria (PRSD) requires distances d_a and d_b to be 180 ft and 130 ft respectively. The available sight distance for drivers on approach A, when they are 180 ft away from the intersection point, is how much distance they can see from approach B divided by the required distance which is 130 ft. So, according to the geometry shown in the figure, distance a = 10 + 10 + 12 - 1 = 31 ft., and distance b = 10 + 10 + 12 + 1 = 33 ft. The available sight distance for drivers on approach A is

$$ASD = \left(\frac{a\ d_a}{d_a - b}\right)\left(\frac{1}{d_b}\right)$$

$$ASD = \left(\frac{31 * 180}{180 - 33}\right)\left(\frac{1}{130}\right) = 0.29$$

Solution 2:

If approach A is stop controlled, then the crossing sight distance criteria (CRSD) require distance d_b to be 300 ft because the design speed of approach B is 30 mph (see Figure 5). The drivers on approach A are assumed to stop 10 ft before the edge of the intersection. The distance between the driver and the front of the vhicle is assumed to be 8 ft. So, the total distance between the driver and the edge of the intersection is 18 ft. According to the geometry shown in Figure 7, the distance d_a in this case is

$$18 + 10 + 12 + 1 = 41$$

The available sight distance for drivers on approach A is

$$ASD = \left(\frac{a\ d_a}{d_a - b}\right)\left(\frac{1}{d_b}\right)$$

$$ASD = \left(\frac{31 * 41}{41 - 33}\right)\left(\frac{1}{300}\right) = 0.53$$

The same procedure is used to calculate the available sight distance with respect to obstructions on the left. The minimum of the two will be taken as the avialable sight distance.

Chapter 5

ANALYSIS OF DATA

Data was coded according to the coding manual shown in Appendix C. The coded data has been thoroughly checked and put on the computer disc. Both SPSS (Statistical Package for the Social Sciences) (22) and SAS (Statistical Analysis System) (23) were used for analysis of data. Appendix D gives the frequency tables for the categorical variables that were used in this study.

The following is a description of the analysis used for achieving the objectives:

5.1 Reliability of Traffic Conflict Counts

In this study, there were seven conflict observers. In order to check for the reliability of each observer, two checks were done. The first check was done during the initial phases of data collection. The second was done towards the end of data collection.

In the first check, a comparison was done between some of the observers. Two observers were used for counting the conflicts for the same approach at the same time for 40 minutes. This check revealed that the difference is very small between the observers.

In the second check, the seven observers counted the conflicts for one approach at the same time for one hour. The counted conflicts were then grouped into the following two categories:

1. Rear End and Side Swipe Accident Causing Conflicts. This includes the following types of conflicts: left turn same direction, right turn same direction, slow vehicle through direction, and lane change.
2. Right Angle Accident Causing Conflicts. This includes the following types of conflicts: opposing left turn, left turn from right, right turn from right, cross traffic from left, cross traffic from right, and left turn from left.

After comparing these two groups for the observers, it was found that one observer was undercounting the right angled conflicts. So, a thorough check on this observer's previous work was made. Most of his observations were deleted and repeated later.

5.2 Preliminary Analysis

To have a preliminary idea about the data, various tables and graphs were obtained. These tables and graphs are presented in the following subsections. It must be pointed out that the mentioned differences may be due to the effects of other variables. Therefore these simple analysis should be treated only as a cursory look on the data.

5.2.1 Overall View of Conflicts at all intersections

Table 6 shows the average number of conflicts for each type of conflicts for different control and intersection types. This table shows that Left turn from right, Left turn from left, Crossing from left, and crossing from right have relatively higher number of conflicts with respect to the others. One reason for this may be insufficient sight distance, which made it difficult for the drivers to see the crossing street clearly. This table also shows that stop control at cross intersections seems to reduce left turn same direction, right turn same direction, lane change, left turn from left, and crossing from right conflicts, however, it increases the number of conflicts for the other conflict types. T or Y intersections, in general, have less number of conflicts than cross intersections because of the limited number of conflicting movements in 3-legged intersections. The simple nature of 3-legged intersections results in three major conflict points compared to 16 for 4-legged intersections as indicated in Figure 8.

As it is observed in Table 6, occurrences of most of the conflicts during 40 minute intervals are very infrequent. Therefore doing analysis with these observations may not lead to conclusive and statistically reliable results. Also the reliability of the individual conflict observations will be lower than the sum of conflicts for a related group of conflicts, as it is a well known phenomenan in mesaurement theory (25). Therefore to improve the reliability and to increase the probability of observing conflicts the individual conflict types were grouped into: 1. Rear end and

Table 6 : Average Number of Conflicts Per 40 Minutes (Standard Deviation)

Conflict Group	All	Uncontrolled			Stop Controlled		
Conflict Type	Inter-sections	ALL	Cross	T/Y	ALL	Cross	T/Y
1. *Rear-End and Side Swipe Accident Causing Conflicts*							
- Left turn same direction	0.18 (0.60)	0.22 (0.66)	0.16 (0.37)	0.24 (0.76)	0.06 (0.25)	0.00 (0.00)	0.13 (0.34)
- Right turn same direction	0.14 (0.52)	0.17 (0.58)	0.16 (0.37)	0.18 (0.65)	0.03 (0.18)	0.06 (0.25)	0.00 (0.00)
- Slow vehicle through direction	0.13 (0.63)	0.06 (0.27)	0.09 (0.39)	0.04 (0.20)	0.38 (1.19)	0.75 (1.62)	0.00 (0.00)
- Lane change	0.06 (0.24)	0.07 (0.25)	0.09 (0.30)	0.05 (0.23)	0.03 (0.18)	0.00 (0.00)	0.06 (0.25)
2. *Right-Angled Accident Causing Conflicts*							
- Opposing Left-Turn	0.17 (0.58)	0.19 (0.62)	0.19 (0.65)	0.19 (0.61)	0.13 (0.42)	0.25 (0.58)	0.00 (0.00)
- Right Turn from Right	0.15 (0.41)	0.16 (0.44)	0.13 (0.42)	0.18 (0.45)	0.09 (0.30)	0.19 (0.40)	0.00 (0.00)
- Left Turn from Left	0.32 (1.41)	0.42 (1.60)	0.06 (0.25)	0.57 (1.89)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
- Left Turn from Right	0.40 (0.96)	0.33 (0.89)	0.22 (0.61)	0.38 (0.99)	0.63 (1.16)	0.75 (1.39)	0.50 (0.89)
- Crossing from Left	0.28 (0.69)	0.21 (0.55)	0.47 (0.80)	0.10 (0.34)	0.53 (1.02)	0.75 (1.34)	0.31 (0.48)
- Crossing from Right	0.25 (0.67)	0.21 (0.64)	0.69 (1.03)	0.00 (0.00)	0.41 (0.76)	0.63 (0.96)	0.19 (0.40)

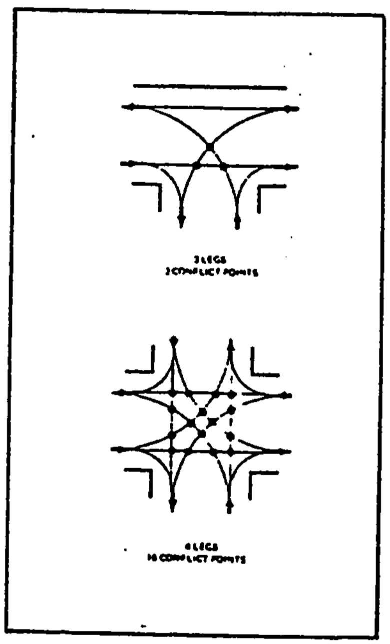


Figure 8 : Conflict Points in T and Cross Intersections

Source : Reference (24), p. 4.1-6

side swipe accident causing conflicts (shortly, rear end conflicts) and 2. Right angled accident causing conflicts (shortly right angled conflict). The types of conflicts included in these conflict groups were mentioned in Section 5.1.

Table 7 shows the average number of rear end and side swipe conflicts, right angled conflicts, total conflicts and their rates respectively. This table shows that all conflicts at stop controlled cross intersections are more than that of the uncontrolled ones. But for T or Y intersections the reverse is true. The reason for this is that the stop control is mostly put at the middle leg of the 3 legged intersections. The drivers coming on the middle leg are mostly cautious and careful. This table also shows that cross intersections have more conflicts than T or Y intersections regardless of the type of the control. This is expected. As was mentioned before, T or Y intersections have less number of conflicting movements than cross intersections which results in less number of conflicts.

5.2.2 Effect of Sight Distance on Conflicts

Several graphs were drawn to see type of relationships between the two types of conflicts and different sight distance criteria for each type of control as shown in Figures 9 through 14. Due to limitation of space, only the ones with good relationships and that were significant in regression models, as discussed later, are presented. From these figures, it was found that right

Table 7 : Average Number of Conflicts and Conflicts Rate Per 40 Minutes (Standard Deviation)

Conflict Group	All	Uncontrolled			Stop Controlled		
Conflict Type	Inter-sections	ALL	Cross	T/Y	ALL	Cross	T/Y
Rear End and Side Swipe Conflicts	0.51 (1.03)	0.51 (0.99)	0.50 (0.76)	0.51 (1.08)	0.50 (1.19)	0.81 (1.60)	0.19 (0.40)
Right Angled Conflicts	1.57 (2.56)	1.51 (2.48)	1.75 (2.82)	1.41 (2.33)	1.78 (2.84)	2.56 (3.76)	1.00 (1.10)
Total Conflicts	2.08 (3.11)	2.02 (2.96)	2.25 (3.12)	1.92 (2.90)	2.28 (3.60)	3.38 (4.76)	1.19 (1.28)
Rear End and Side Swipe Conflicts Rate x 10^2	2.70 (6.30)	2.31 (4.47)	3.22 (4.87)	1.92 (4.26)	3.97 (10.3)	7.17 (13.9)	0.76 (1.64)
Right Angled Conflicts Rate x 10^2	9.99 (15.1)	8.59 (12.3)	10.8 (15.0)	7.64 (10.9)	14.6 (21.6)	23.0 (27.8)	6.20 (5.82)
Total Conflicts Rate x 10^2	12.7 (18.3)	10.9 (14.2)	14.0 (16.9)	9.56 (12.8)	18.6 (27.4)	30.2 (35.0)	6.96 (6.07)

Note : Conflicts rate means conflicts divided by approach volume

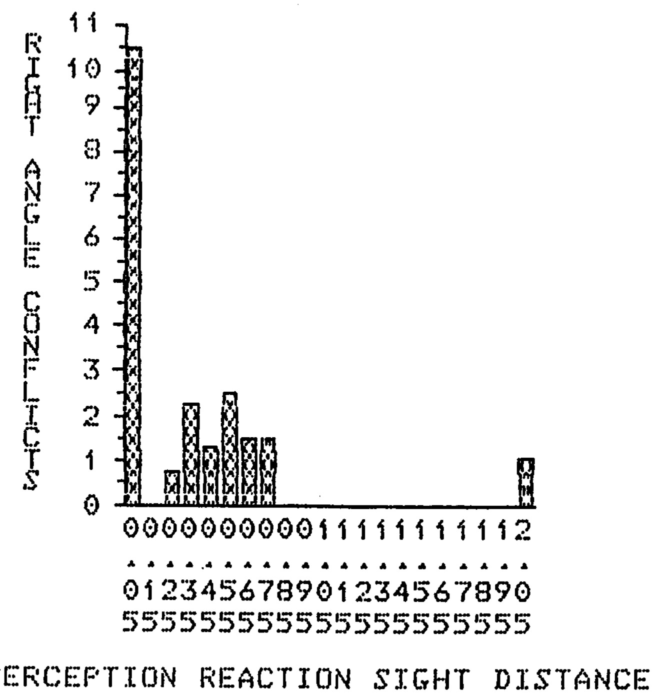


Figure 9 Effect of Perception Reaction Sight Distance on Right Angled Conflicts at Uncontrolled Approaches

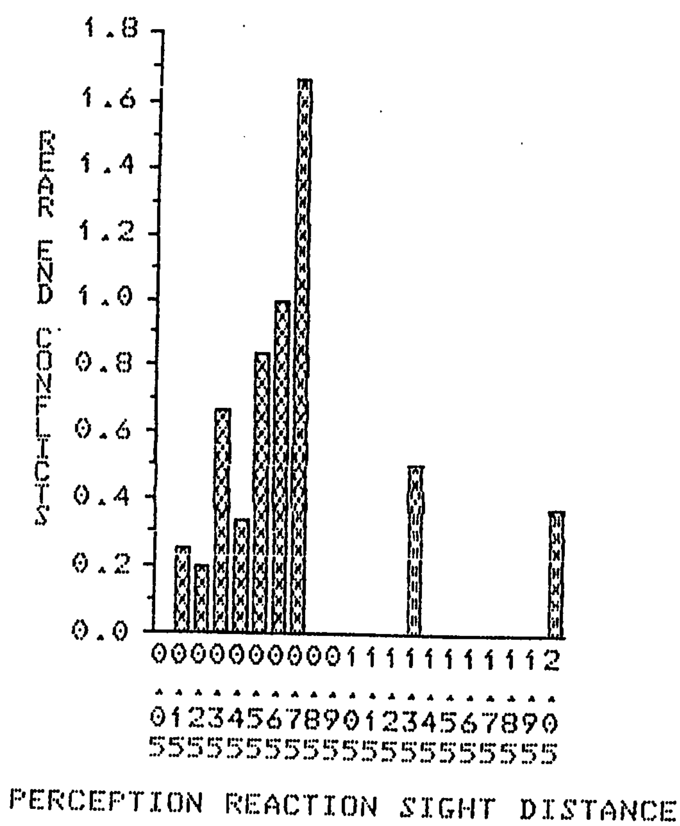


Figure 10 Effect of Perception Reaction Sight Distance on Rear End Conflicts at Uncontrolled Approaches

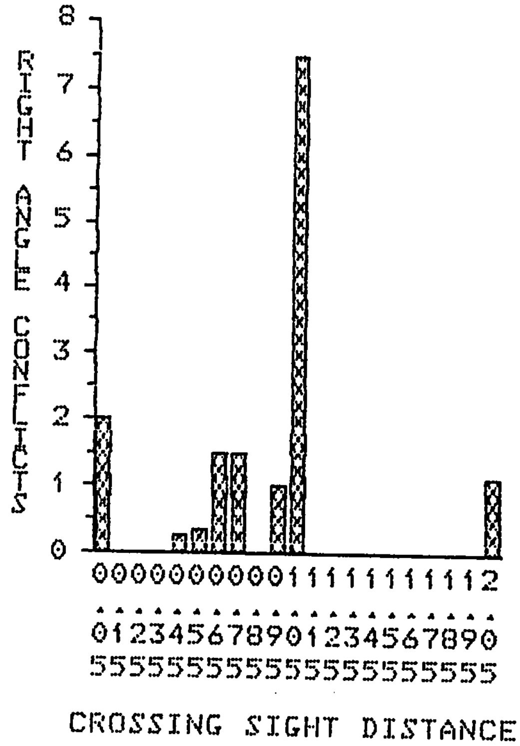


Figure 11 Effect of Crossing Sight Distance on Right Angled Conflicts at Stop controlled Approaches

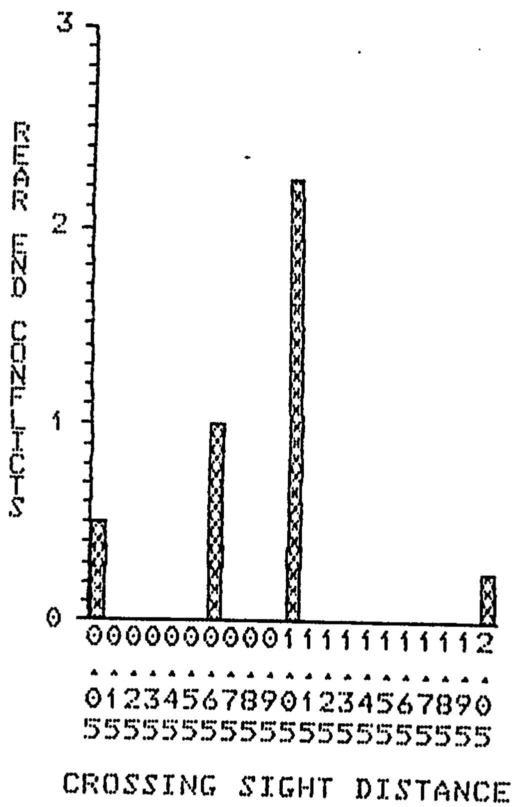


Figure 12 Effect of Crossing Sight Distance on Rear End Conflicts at Stop controlled Approaches

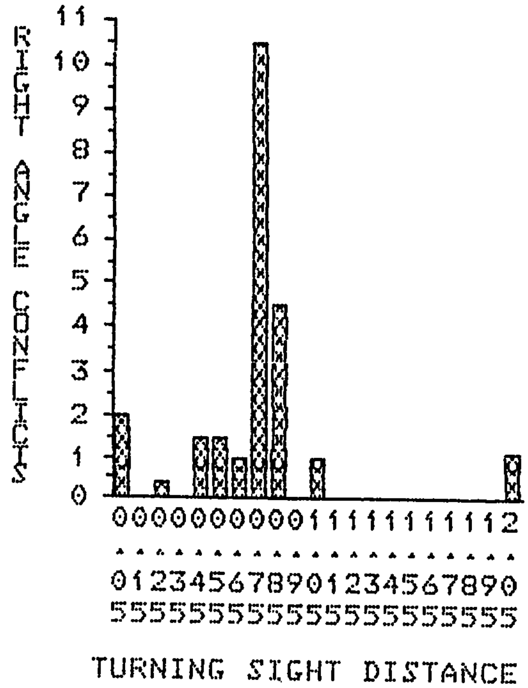


Figure 13 Effect of Turning Sight Distance on Right Angled Conflicts at Stop controlled Approaches

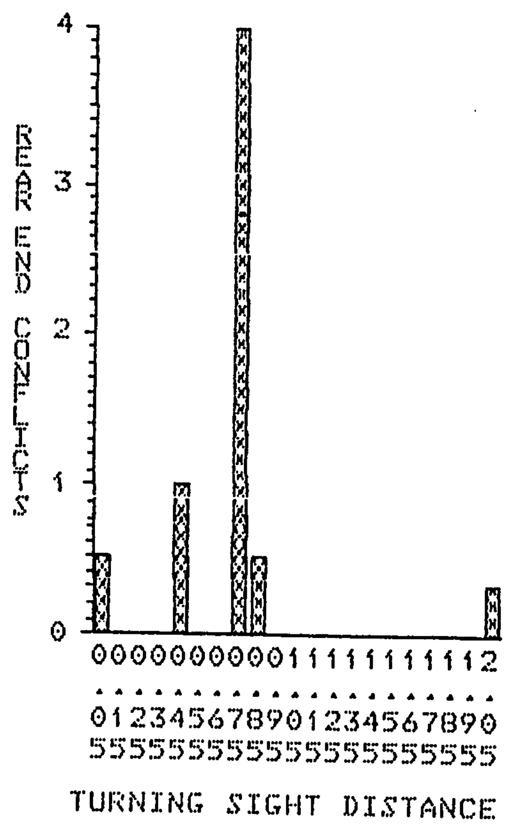


Figure 14 Effect of Turning Sight Distance on Rear End Conflicts at Stop controlled Approaches

angled conflicts and rear end conflicts at uncontrolled approaches are best related to the available perception reaction sight distance (PRSD) which is the criterion defined by AASHTO for uncontrolled approaches. At stop controlled approaches, right angled conflicts and rear end conflicts are related to both the available crossing sight distance (CRSD) and the available turning sight distance (TUSD) which are the criteria defined by AASHTO for stop controlled approaches.

Figure 9 shows the relation between right angled conflicts and the available perception reaction sight distance (PRSD) for uncontrolled approaches. This figure shows that as PRSD increase right angled conflicts decrease. Rear end conflicts at uncontrolled approaches, as can be seen in Figure 10, has a different relation with PRSD. As PRSD increases rear end conflicts increase up to a certain limit, approximately 0.75 of PRSD, after that, rear end conflicts drop down. This behavior can be explained. When sight distance is restricted, drivers approach the intersection very carefully and possibly at low speeds making less rear end conflicts. However as PRSD increases, drivers become overconfident for the situation and tend to speed up because they think that they can see the crossing traffic clearly. But soon they realize that they have to slow down causing more rear end conflicts. And as PRSD exceeds 0.75, the crossing traffic is now becoming clearer because sight distance now is sufficient which results in less rear end conflicts.

The same behavior was found for stop controlled approaches for both right angled and rear end conflicts, as can be seen in Figures 11 thorugh 14. The same argument that was mentioned for rear end conflicts at uncontrolled approaches can be repeated here with different peak points, 0.75 for TUSD and 1.05 for CRSD for both rear end and right angled conflicts. Rear end conflicts and right angled conflicts increase as CRSD increase from zero to 1.05 or as TUSD increase from zero to 0.75, after that, conflicts start to decrease.

5.2.3 Effect of Traffic Volumes on Conflicts

Figures 15 through 18 show the relationship between rear end conflicts and right angled conflicts with approach volume per 40 minutes for uncontrolled and stop controlled approaches. At uncontrolled approaches, rear end conflicts increase as approach volume increase, while right angled conflicts increase as approach volume increases up to approximately 400 vehicles per 40 minutes (600 vehicles per hour, VPH), after which right angled conflicts start to decrease. The reason for this behavior may be that when the approach volume is low, the crossing traffic have freedom or enough gaps to cross making few right angled conflicts. But when the approach volume increase up to 300 to 500 vehicles per 40 minutes (450 to 750 VPH), gaps are shortened and the cross traffic now have partial freedom to cross making more right angled conflicts. However, as the approach volume increases

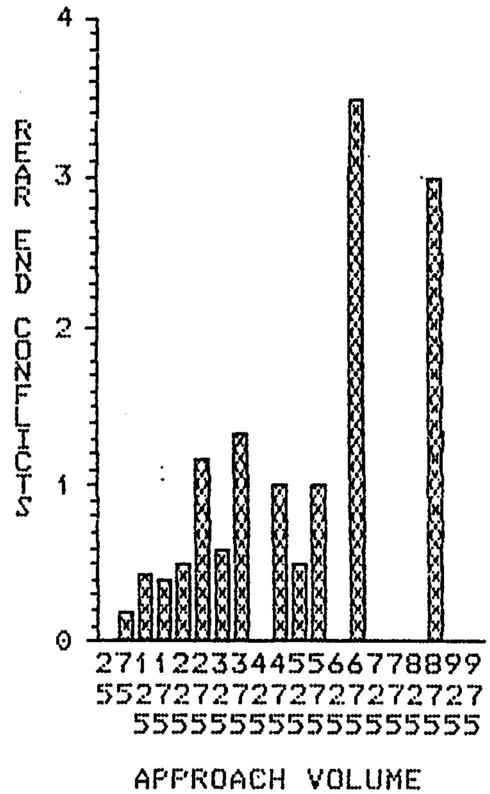


Figure 15 Effect of Approach Volume on Rear End Conflicts at Uncontrolled Approaches

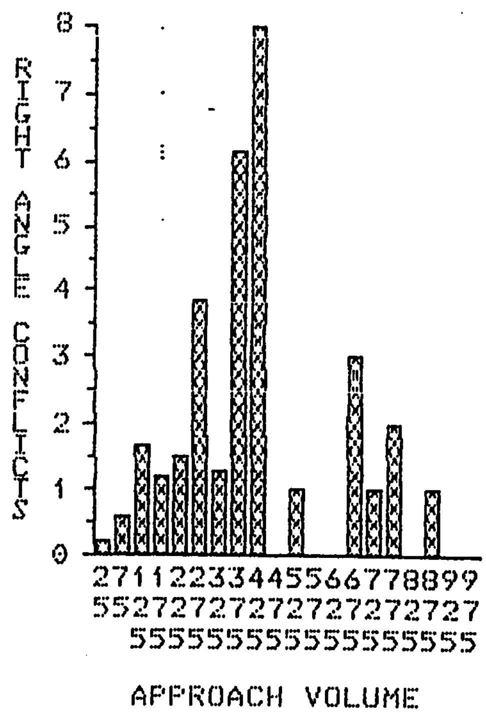


Figure 16 Effect of Approach Volume on Right Angled Conflicts at Uncontrolled Approaches

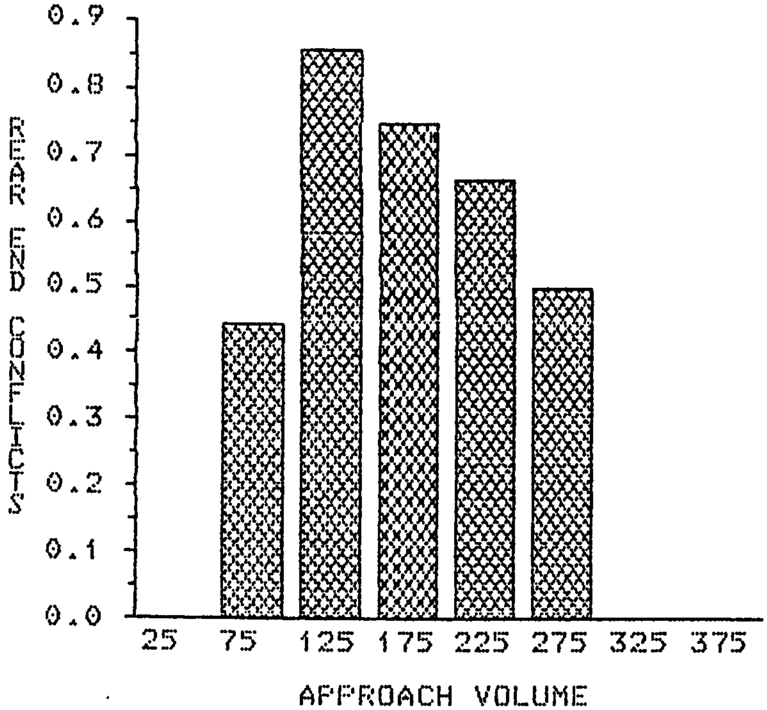


Figure 17 Effect of Approach Volume on Rear End Conflicts at Stop controlled Approaches

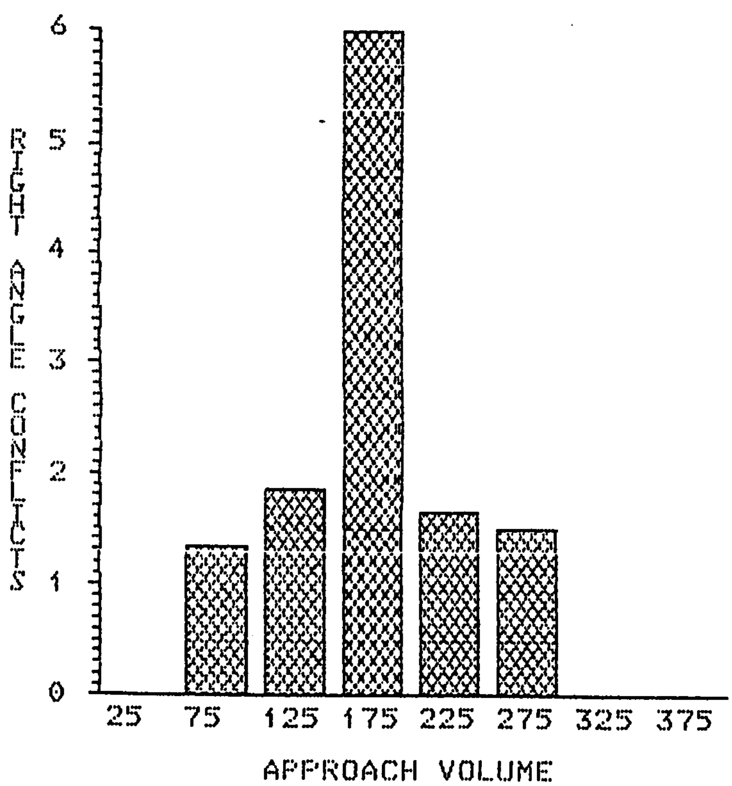


Figure 18 Effect of Approach Volume on Right Angled Conflicts at Stop controlled Approaches

beyond 500 vehicles per 40 minutes, the approach will behave as if it is a major street, so the crossing traffic will cross very carefully, making less right angled conflicts.

At stop controlled approaches, the relation is similar for right angled conflicts, but different for rear end conflicts, as can be seen in Figures 17 and 18. Rear end and right angled conflicts increase as approach volume increase from zero to approximately 150 vehicles per 40 minutes)(225 VPH), after which conflicts start to decrease.

Figures 19 and 20 show the relationships between rear end conflicts and right angled conflicts with crossing volume for uncontrolled approaches. These figures indicate that there is no observable relationship between conflicts and crossing volume for uncontrolled approaches. This finding was confirmed when regression analysis was done.

Figures 21 and 22 show the relationships between the same variables but for stop controlled approaches. These figures indicate that maximum conflicts occur when the crossing volume is equal to 450 vehicles per 40 minutes (675 VPH) approximately.

5.3 Developing Relationships between Conflicts and Other Variables

The above mentioned analysis revealed that some relationships between conflicts and other variables such as sight distance and volumes were nonlinear. For some, the relationships resem-

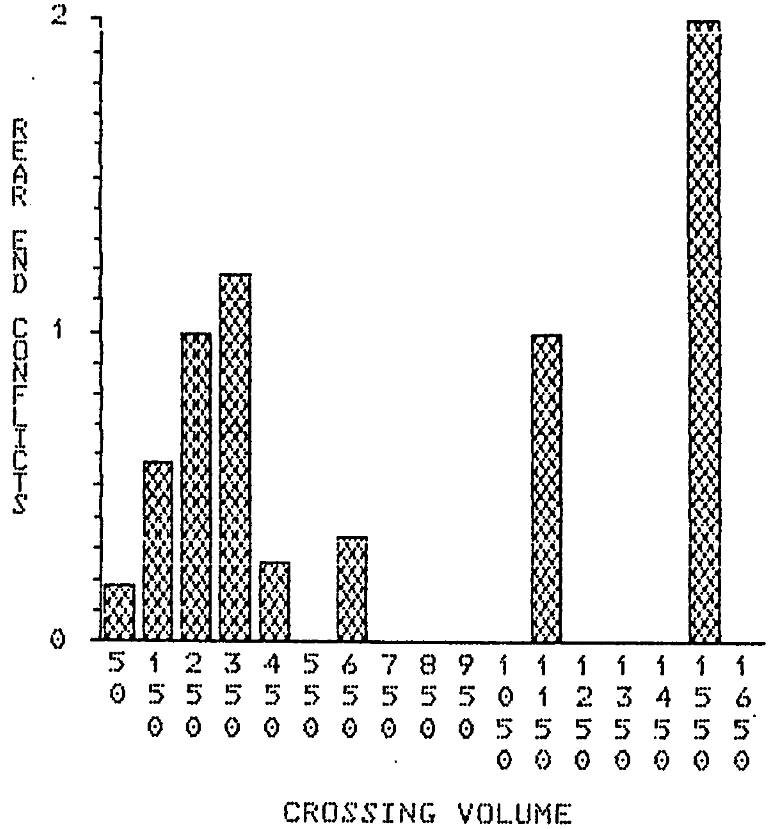


Figure 19 Effect of Crossing Volume on Rear End Conflicts at Uncontrolled Approaches

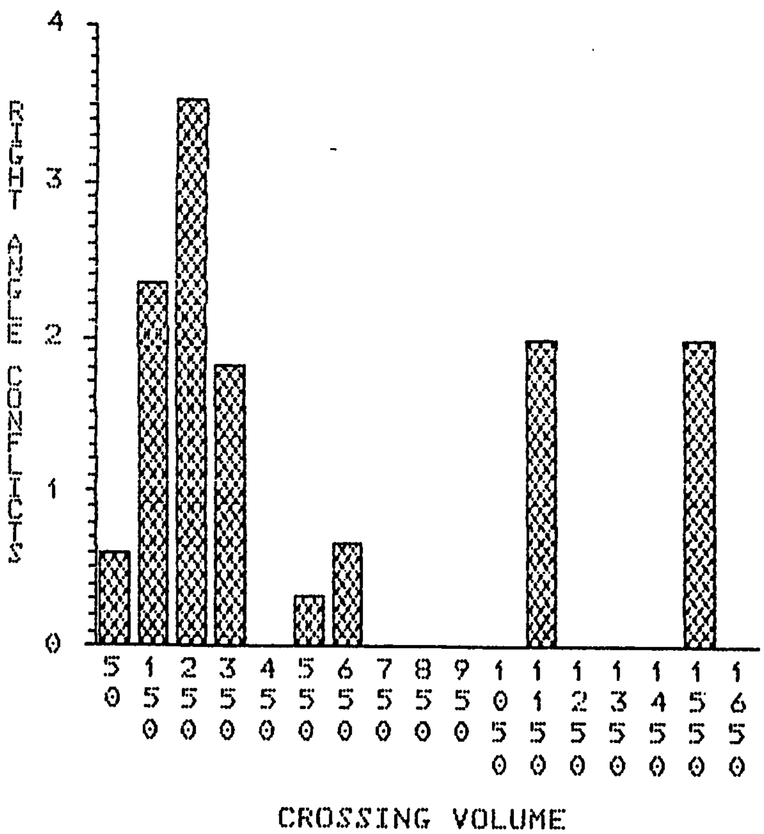


Figure 20 Effect of Crossing Volume on Right Angled Conflicts at Uncontrolled Approaches

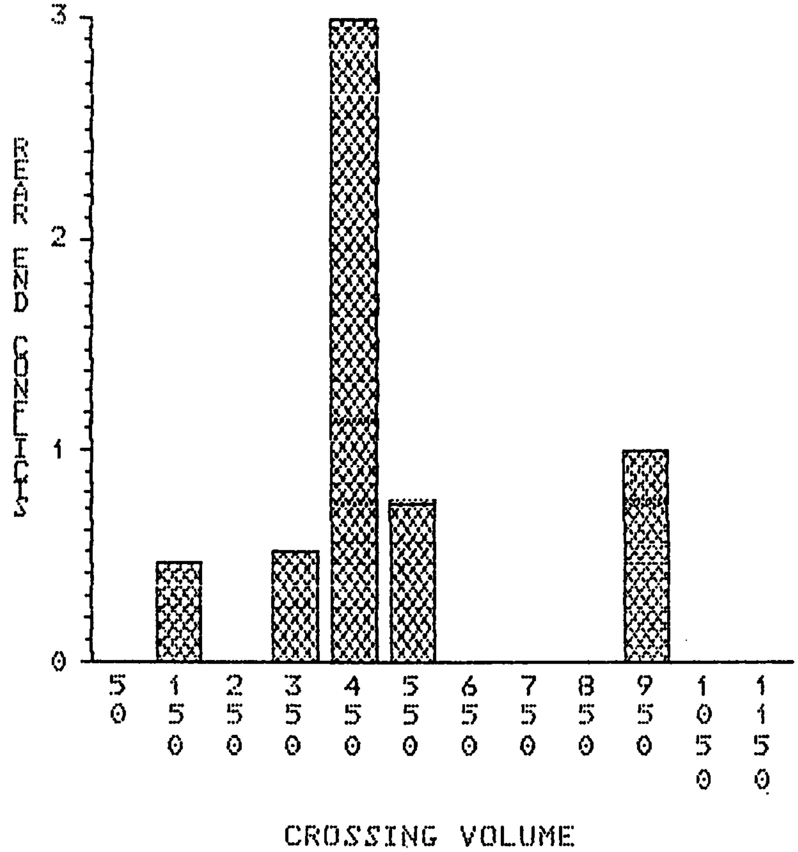


Figure 21 Effect of Crossing Volume on Rear End Conflicts at Stop controlled Approaches

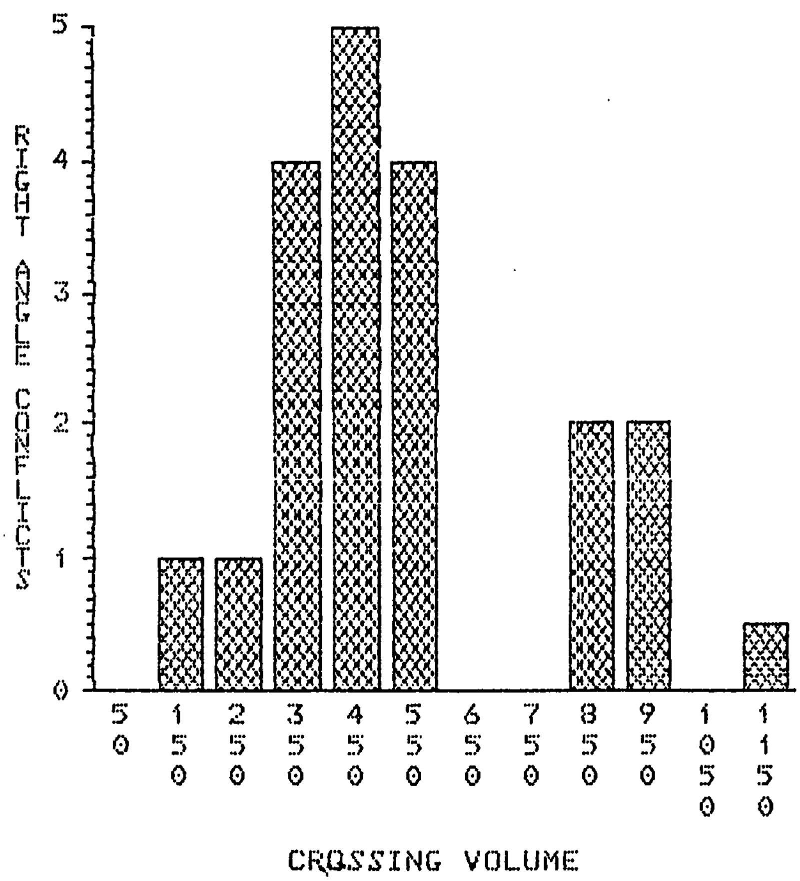


Figure 22 Effect of Crossing Volume on Right Angled Conflicts at Stop controlled Approaches

bled the normal distribution. Therefore transformations for these relationships had to be made.

5.3.1 Considered Parameters

The transformed variables were selected in such a way to give the highest correlations with conflicts. For example, the relationships between conflicts and crossing sight distance at stop controlled approaches were similar to the normal distribution with 1.05 as the peak point which corresponds to the mean value of the distribution (see Figures 11 and 12). So, in deriving the new form for this variable, the following equation was tried:

$$e^{-a(CRSD-1.05)^2}$$

This equation is a normal curve equation. Several values of "a" were tried. The value that gave the highest correlation with conflicts was selected. In this example the value of "a" was 100.

The relationship between rear end conflicts and the available perception reaction sight distance at uncontrolled approaches was also similar to normal distribution, with a peak point at 0.75, as was shown in Figure 10. The normal curve equation was tried, but the resulting correlation was not high. So the data was divided into two groups. The first group is from 0 to 0.75 of PRSD. The second group is from 0.76 to the highest value. For the first group, it was found that rear end conflicts are highly correlated with $PRSD^4$. But for the second group, rear end conflicts were highly correlated with the reciprocal of $PRSD^2$. So the new form of the transformed variable PRSD is $PRSD^4$ when PRSD is less than or equal to 0.75 and $1/PRSD^2$ when PRSD is greater than 0.75, as shown in Table 8.

The other new forms of the other variables are derived the same way and listed in Table 8.

5.3.2 Investigation of the Relationships between Conflicts and other Independent Variables

In this study, three statistical techniques were used. These techniques are Multiple Regression Analysis , Analysis of Variance (ANOVA) and Covariance , and Multiple Classification Analysis. Appendix E gives a summary of these statistical techniques.

5.3.2.1 Developing Conflict Regression Models

In order to have a better understanding about the relationships between the traffic conflicts and other variables, multiple regression analysis have been carried out. Explanations of the variables used are given in Table 8. The dependent variable is the 40-minutes conflict counts. For categorical variables "zero" is used when the indicated variable does not exist and "one" when it does. The resulting models for uncontrolled and stop controlled approaches are given in Tables 9 and 10 respectively. It should be noted that separate models for right angled and rear end con-

Table 8 : **Explanation of the Variables Used in Regression Models**

Variable	*Explanation*
PRSD	Available Perception Reaction Sight Distance
NPRSD	$PRSD^4$ when $0 < PRSD < 0.75$, $1/PRSD^2$ when $PRSD > 0.75$
PRSD11	1/PRSD
CRSD	Available Crossing Sight Distance
TUSD	Available Turning Sight Distance
NEWCRSD	$Exp(-100\ (CRSD - 1.05)^2)$
NEWTUSD	$Exp(-950\ (TUSD - 0.75)^2)$
AA	$Exp(-0.1\ (\text{Approach Volume} - 150)^2)$
AA1	$Exp(-0.00062\ (\text{Approach Volume} - 400)^2)$
CC	$Exp(-0.001\ (\text{Crossing Volume} - 450)^2)$
LEFRIG	Total of Left and Right Turns in the Intersection
SPEED	Average Speed (KPH)
DTYPE	Type of intersection, "0" when T-intersection and "1" when cross intersection
APPWIDTH4	$(\text{Approach width})^4$

Note : Volumes are in vehicles per 40 minutes.

Table 9 : Regression for Uncontrolled Approaches

Variables	*Coefficient Estimates (Significance)*	
	Rear End and Side Swipe Conflicts	*Right Angled Conflicts*
Intercept	-0.243	-0.8328
NPRSD	1.712 (0.0001)	-
PRSD11	-	0.2231 (.0028)
AA1	-	4.531 (0.0001)
LEFRIG	0.00231 (.0001)	5.506x10 -3 (0.0001)
DTYPE	0.346 (0.0424)	0.959 (.0259)
Overall Test Statistics		
R^2	0.422	0.451
F(signif)	24.86 (.0001)	20.74 (.0001)

Table 10 : **Regressions for Stop Controlled Approaches**

Variables	*Coefficient Estimates (Significance)*			
	Rear End and Side Swipe Conflicts		*Right Angled Conflicts*	
	Using NEWCRSD	Using NEWTUSD	Using NEWCRSD	Using NEWTUSD
Intercept	-1.555	-0.693	-0.4256	1.118
NEWCRSD	2.279 (.0005)	-	4.2395(.0001)	-
NEWTUSD	-	4.805 (.0001)	-	9.591 (.0001)
AA	-	-	47.679 (.0001)	31.318 (.0023)
CC	9.11 (.0020)	5.461 (.0368)	10.297 (.0068)	-
SPEED	0.0391 (.0196)	0.0208 (.1049)	-	-
APPWIDTH4	-	-	7.898x10 -5 (.0524)	-
Overall Test Statistics				
R^2	0.561	0.676	0.876	0.788
F(signif)	11.91 (.0001)	19.47 (.0001)	47.88 (.0001)	53.78 (.0001)

flicts were built because of the different effects of some variables on each conflict type.

As shown in Table 9, each parameter in both models is significant within 5 percent level. The total number of observations is 106. R^2 value for rear end conflicts model is 0.422, which means that 42.2 percent of the variation in rear end conflicts is explained by the model. Similarly, 45.1 percent of the variation in right angled conflicts is explained by the right angled conflicts model.

This table shows that right angled conflicts at uncontrolled approaches decrease as PRSD increase because they were found to be positively correlated to 1/PRSD. They also increase as total left and right turns in the intersection increase and when the intersection is cross intersection. The dummy variable that was used here is DTYPE. For cross intersections, DTYPE equals to one, for T or Y intersections, DTYPE equals to zero. Another variable that was significant in this model is AA1, which is a transformed form of approach volume. As can be seen in Table 8, the value of AA1 increases as approach volume is closer to 400 vehicles per 40 minutes (600 vehicles per hour, VPH) approximately. This means that as approach volume increases up to 600 VPH right angled conflicts increase, after that conflicts decrease with increasing the approach volume. The reason for this behavior is that when the approach volume is low, 0 to 300 vehicles per 40 minutes (450 VPH) approximately, right angled conflicts are rare because the gaps that are available for the conflicting movements are long. But as the volume increases, gaps become shorter which results in more right angled conflicts. However, as the approach volume exceeds 500 vehicles per 40 minutes (750 VPH), the approach behaves as a major street, so the drivers on the crossing street will be cautious and alert which results in less right angled conflicts.

Rear end and side swipe conflicts model shown in Table 9 indicates that conflicts at uncontrolled approaches increase as left and right turns increase and if the intersection is a cross intersection. The new form of PRSD was significant in this model at 0.0001 level and positively related. This new form, which is NPRSD, equals to $PRSD^4$ when PRSD is in the range of 0 to 0.75 and $1/PRSD^2$ when PRSD is greater than 0.75. This means that as PRSD increase from 0 to 0.75, rear end conflicts increase, however, as it increases beyond 0.75, conflicts decrease as was figured out in the preliminary analysis.

For stop controlled approaches, several models were tried using TUSD and CRSD. The resulting models are shown in Table 10. Only one model for rear end and side swipe conflicts and another model for right angled conflicts should be selected. As can be seen in this table, using NEWCRSD gives marginally better models in terms of R^2 for right angled conflicts and marginally inferior model for rear end conflicts compared to models with NEWTUSD. Since there were more significant explanatory variables in models with NEWCRSD, models with NEWCRSD were selected for further analysis.

As shown in Table 10, each variable in both models is significant within 5 percent level. The total number of observations is 32. R^2 value for rear end conflicts model is 0.561, which means that 56.1 percent of the variation in rear end conflicts is explained by the model. Similarly, 87.6 percent of the variation in right angled conflicts is explained by the right angled conflicts model.

The functional form of the variable NEWCRSD is that of a normal distribution function. This means that both rear end and right angled conflicts increase up to a critical value of CRSD, which is 1.05, after that they decrease with increasing the value of CRSD.

Rear end and right angled conflicts at stop controlled approaches were also affected by crossing volume. The type of relationships is that of a normal distribution function, with a peak point of 450 vehicles per 40 minutes (675 VPH) approximately. This means that both rear end and right angled conflicts increase to a critical value of crossing volume, which is 675 VPH, and after that they decrease with increasing the crossing volume. The reason for this is that when crossing volume is less than 300 vehicles per 40 minutes (450 VPH) approximately, gaps are long which results in less conflicts. However when the crossing volume is in the range between 300 and 600 vehicles per 40 minutes

(450 and 900 VPH respectively), gaps are shorter, which results in more conflicts. But higher crossing volumes (higher than 600 vehicles per 40 minutes) denote that the crossing stream is a major road which will possibly leave the right of way even without the stop sign. In this case, drivers will be more cautious and alert and will likely obey the stop sign which may result in less conflicts.

Rear end and side swipe conflicts at stop controlled approaches also increase as speed increases. So, speed limits should be enforced in order to improve safety at intersections.

Right angled conflicts are also affected by approach volume and the fourth power of approach width. The approach volume effect is similar to the crossing volume effect. This means that as approach volume is closer to 150 vehicles per 40 minutes (225 vehicles per hour), right angled conflicts increase. The same argument that was made for uncontrolled approaches can be applied here. The last variable that entered into the model was $(\text{approach width})^4$. As approach width increase, right angled conflicts increase.

One interesting finding from the above models is that the type of intersection was only significant at uncontrolled approaches. At stop controlled approaches the type of intersection was not significant. The reason for this is that vehicles at a stop controlled approach have to stop regardless of the type of the intersection. Whereas at uncontrolled T or Y intersections there is an implied right of way. The vehicles entering the intersection from the middle leg assumes that the left and right legs have the right of way and therefore slow down or even stop. Therefore it may be expected that putting a stop sign at T or Y intersections may not be very effective as if it is at cross intersections.

5.3.2.2 Investigation of the Relationships Using ANOVA

After finding the best models using multiple regression, Analysis of Variance (ANOVA) and Covariance for these models was carried out. There are actually two reasons for doing this type of analysis. The first one is to capture the pure additive effects of the categorical variables. The second is to do some simplification for practical applications.

The categorical independent variable that was significant was intersection type for uncontrolled approaches. Therefore, only uncontrolled approaches were analyzed using ANOVA. The results are shown in Table 11. The continuous independent variables were entered as covariates and the categorical independent variables as factors.

As can be seen in this table, the covariates and the type of intersection are significant at 5% level which confirms with what was found by regression analysis.

In Table 12 results of Multiple Classification Analysis (MCA) for uncontrolled approaches are given for the categorical indepen-

Table 11 : ANOVA for Uncontrolled Approaches

Type of Conflicts	*Source of Variation*	*F-Statistics (Significance)*
RACON	Covariates	25.948 (0.000)
	AA1	14.252 (0.000)
	LEFRIG	17.843 (0.000)
	PRSD11	12.888 (0.001)
	Main Effects	5.112 (0.026)
	TYPE	5.112 (0.026)
RECON	Covariates	35.174 (0.000)
	LEFRIG	17.613 (0.000)
	NPRSD	24.831 (0.000)
	Main Effects	4.223 (0.042)
	TYPE	4.223 (0.042)

Note : RACON is Right Angled Conflicts
RECON is Rear End and Side Swipe Conflicts

Table 12 : Multiple Classification Analysis for Uncontrolled Approaches

Type of Conflicts *(Grand Mean Conflicts/40 min)*	*Categorical Variables* *- Categories (Number of Cases)*		*Deviations from Mean* *Unadjusted for Covariates (ETA)*	*Adjusted for Covariates (Beta)* *(R^2)*
RACON	Intersection Type			
(1.51)	T/Y	(74)	-0.10	-0.29
	Cross	(32)	0.24	0.67
			(0.06)	(0.18)
				(0.451)
RECON	Intersection Type			
(0.51)	T/Y	(74)	0.00	-0.10
	Cross	(32)	-0.01	0.24
			(0.01)	(0.16)
				(0.422)

Note : RACON is Right Angled Conflicts
RECON is Rear End and Side Swipe Conflicts

dent variable type of intersection. The effect of type of intersection is shown in the table with and without adjustment for covariates. The pure effect of the type of intersection are given in the column of "deviations from mean adjusted for covariates". The difference between conflicts at T and cross intersections increase when it is adjusted for the covariates. Sometimes the sign changes, as can be seen for rear end conflicts. The pure effect of intersection type indicates that conflicts are more when having cross intersection which also confirms with what was found by multiple regression.

Three useful statistics, ETA, BETA and R^2 are also given in Table 13. ETA^2 indicates the proportion of variation in Y explained by the factor. $BETA^2$ indicates the same thing, but after controlling for other factors and covariates. R^2, as in regression analysis, indicates the proportion of variation by all factors and covariates.

Using $BETA^2$ values it can be seen that 3.24 (= 0.18^2 x 100) percent of variance in right angled conflicts and 2.56 (= 0.16^2 x 100) percent of the variance in rear end conflicts are explained by type of intersection. 42.2% and 45.1% of variance is explained by all the factors and covariates in rear end and right angled conflicts respectively.

5.4 Pure Effects of Sight Distance

For practical considerations, it was decided to use sight distance as a categorical variable. The range of each category was chosen in such a way that the critical region was one category, and all the remaining part was another category. The list of critical ranges are given in Table 13.

Table 14 shows the analysis of variance for uncontrolled approaches. As can be seen in this table, sight distance is significant at 1.2% level for right angled conflicts and 11.5% for rear end conflicts. Table 15 shows the pure effects of type of intersection and sight distance for uncontrolled approaches for rear end and right angled conflicts. Approximately 3.24 and 4.41 percent of variance in right angled conflicts are explained by intersection type and sight distance respectively, whereas 1.69 and 2.25 percent of variance in rear end conflicts are explained by intersection type and sight distance respectively.

Similarly Table 16 shows the analysis of variance for stop controlled approaches. Sight distance is significant at 0.3% level for right angled conflicts and 4.5% level for rear end conflicts. Table 17 shows the pure effects of sight distance for stop controlled approaches for rear end and right angled conflicts. Around 9 percent of variance in right angled conflicts is explained by CRSD. And 9.6 percent of variance in rear end conflicts is explained by CRSD.

Table 18 is a summary of the pure effects of sight distance for uncontrolled and stop controlled approaches which are found by adding the additive main effects (adjusted deviations) to the

Table 13 : **Critical and Not Critical Ranges for Sight Distance**

Conflict Group	*Ranges of Sight Distance*
Right Angled Conflicts	PRSD[1] 1. Critical when PRSD < 0.4 2. Not critical when PRSD > 0.4
Rear End Conflicts	PRSD 1. Critical when 0.50 < PRSD < 0.90 2. Not critical otherwise
Right Angled and Rear End Conflicts	CRSD[2] 1. Critical when 0.75 < CRSD < 1.25 2. Not critical otherwise

[1] PRSD = Perception Reaction Sight Distance is used for Uncontrolled Intersections

[2] CRSD = Crossing Sight Distance is used for Stop Controlled Intersections

Table 14 : ANOVA for Uncontrolled Approaches

Type of Conflicts	*Source of Variation*	*F-Statistics (Significance)*
RACON	Covariates	31.583 (0.000)
	AA1	35.902 (0.000)
	LEFRIG	12.229 (0.001)
	Main Effects	7.493 (0.001)
	TYPE	4.843 (0.030)
	PRSD	6.590 (0.012)
RECON	Covariates	37.184 (0.000)
	LEFRIG	37.184 (0.000)
	Main Effects	2.806 (0.065)
	TYPE	2.370 (0.127)
	PRSD	2.528 (0.115)

Note : RACON is Right Angled Conflicts
RECON is Rear End and Side Swipe Conflicts

Table 15 : **Multiple Classification Analysis for Uncontrolled Approaches**

Type of Conflicts *(Grand Mean Conflicts/40 min)*	*Categorical Variables* *- Categories (Number of Cases)*	*Deviations from Mean* *Unadjusted for Covariates (ETA)*	*Adjusted for Covariates (Beta) (R^2)*
RACON	Intersection Type		
(1.51)	T/Y (74)	-0.10	-0.29
	Cross (32)	0.24	0.67
		(0.06)	(0.18)
	PRSD		
	Critical (48)	0.28	0.57
	Not Critical (58)	-0.23	-0.47
		(0.10)	(0.21)
			(0.437)
RECON	Intersection Type		
(0.51)	T/Y (74)	0.00	-0.09
	Cross (32)	-0.01	0.20
		(0.01)	(0.13)
	PRSD		
	Critical (20)	0.69	0.30
	Not Critical (86)	-0.16	-0.07
		(0.34)	(0.15)
			(0.297)

Note : RACON is Right Angled Conflicts
RECON is Rear End and Side Swipe Conflicts

Table 16 : ANOVA for Stop Controlled Approaches

Type of Conflicts	*Source of Variation*	*F-Statistics (Significance)*
RACON	Covariates	51.510 (0.000)
	AA	90.589 (0.000)
	CC	15.736 (0.000)
	Main Effects	10.267 (0.003)
	CRSD	10.267 (0.003)
RECON	Covariates	14.537 (0.001)
	CC	14.537 (0.001)
	Main Effects	4.393 (0.045)
	CRSD	4.393 (0.045)

Note : RACON is Right Angled Conflicts
RECON is Rear End and Side Swipe Conflicts

Table 17 : **Multiple Classification Analysis for Stop Controlled Approaches**

Type of Conflicts (Grand Mean Conflicts/40 min)	*Categorical Variables - Categories (Number of Cases)*	*Deviations from Mean Unadjusted for Covariates (ETA)*	*Adjusted for Covariates (Beta) (R^2)*
RACON	CRSD		
(1.78)	1 Critical (6)	3.55	1.74
	2 Not Critical (26)	-0.82	-0.40
		(0.61)	(0.30)
			(0.802)
RECON	CRSD		
(0.50)	1 Critical (6)	1.00	0.76
	2 Not Critical (26)	-0.23	-0.17
		(0.41)	(0.31)
			(0.395)

Note : RACON is Right Angled Conflicts
RECON is Rear End and Side Swipe Conflicts

Table 18 : **Summary of the Pure Effects of Sight Distance**

	Right Angled Conflicts			*Rear End and Side Swipe Conflicts*		
	No Control		Stop Control	No Control		Stop Control
	T/Y	Cross	All Inter-sections	T/Y	Cross	All Inter-sections
Critical Sight Distance	1.79	2.75	3.52	0.72	1.01	1.26
Not Critical Sight Distance	0.75	1.71	1.38	0.34	0.64	0.33
% Reduction	58.1	37.8	60.8	51.4	36.6	73.8

grand mean. The percent reductions in conflicts that can be achieved if critical sight distance is taken care of are shown in this table. The percent reduction in right angled and rear end conflicts were around 58.1 and 51.4 for uncontrolled 3-legged approaches, 37.8 and 36.6 percent for uncontrolled 4-legged approaches, 60.8 and 73.8 percent for stop controlled approaches. The total conflict reductions that can be achieved are 56.6, 37.5, and 64.2 percent for uncontrolled T or Y intersections, uncontrolled cross intersections, and stop controlled approaches respectively.

5.5 Practical Applications

The above findings made it possible to calculate the minimum distances to obstructions which results in less conflicts. At uncontrolled approaches, sight distance should be more than 0.90 of the perception reaction sight distance. Whereas at stop controlled approaches, the highest number of conflicts occur when the crossing sight distance is between 0.75 and 1.25. If less than 0.75 of the crossing sight distance is allowed, then the operation of the intersection will be poor, in other words the efficiency will be very low. Sight distance at stop controlled approaches should therefore be more than 1.25 of the crossing sight distance.

Two assumptions were used for the calculation of the minimum distances to the obstructions for uncontrolled approaches.

The first one is that the speeds of the approaches of the intersection are equal. The second assumption is that the distances from the edge of the approaches to the obstruction, X_b or X_d, are equal to the distance from the edge of the crossing street to the obstruction, X_a or X_c, respectively (see Figure 23). These two assumptions will simplify the equations that give X_a, X_b, X_c or X_d. The equations were obtained using simple trigonometry. The derivations are explained in Appendix F. The simplified equations that give these distances for uncontrolled approaches are as follows:

$$X_a = X_b = 0.474\ (PRSD - P_C - LW_C \frac{N_C}{2} - M_c - 1) - 0.526\ (P_A + LW_A - 1)$$

$$X_c = X_d = 0.474\ (PRSD - P_C - LW_C + 1) - 0.526\ (P_A + LW_A \frac{N_A}{2} + M_A + 1)$$

where :

X_a = Distance from the edge of the crossing street to the obstruction

X_b = Distance from the edge of the approach to the obstruction

X_c = Distance from the edge of the crossing street to the obstruction

X_d = Distance from the edge of the approach to the obstruc-

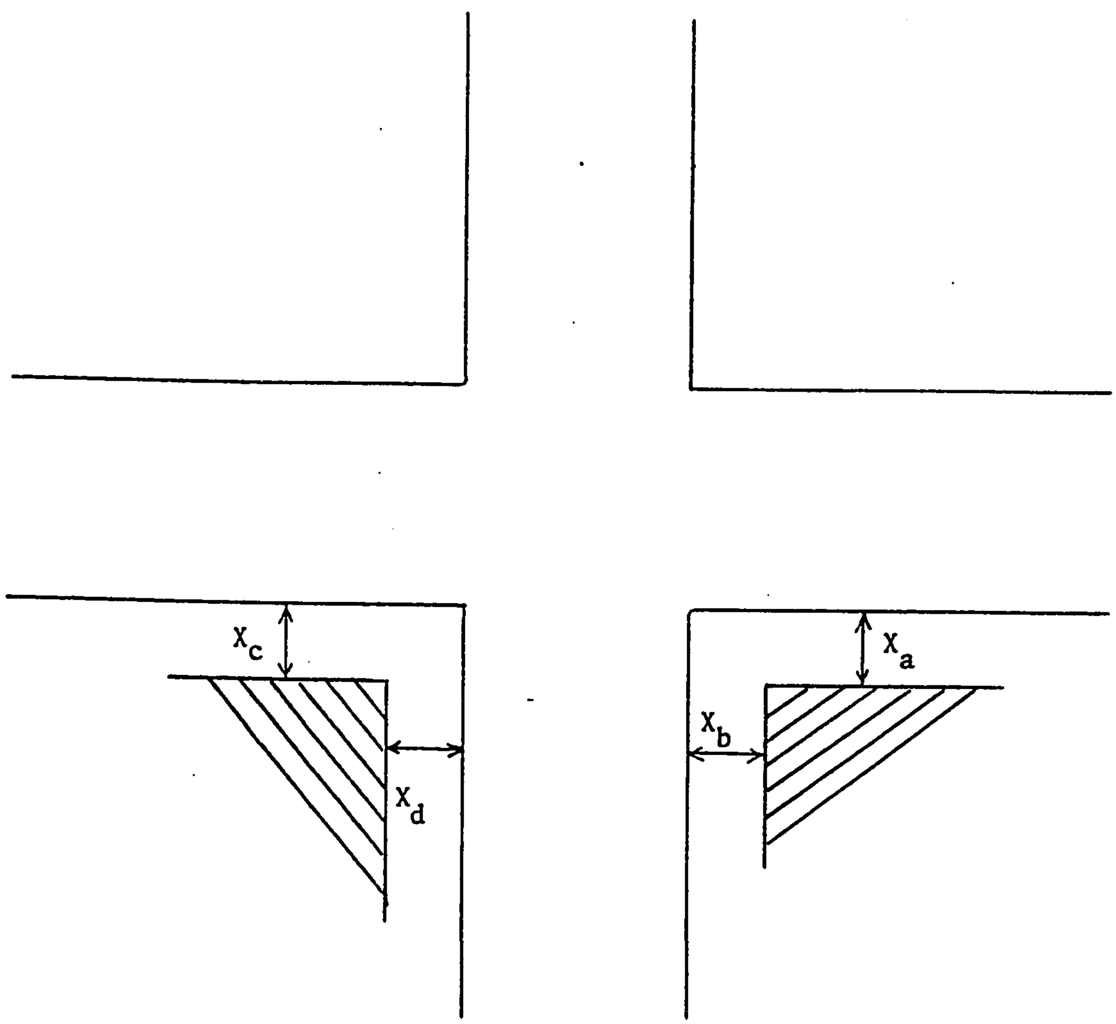


Figure 23 : Distances to Obstructions

tion

PRSD = Perception reaction sight distance in meters

P_A = Parking lane width for the approach (m)

P_C = Parking lane width for crossing street (m)

LW_A = Lane width for the approach (m)

LW_C = Lane width for the crossing street (m)

N_A = Number of lanes for the whole approach

N_C = Number of lanes for crossing street

M_A = Median width for the approach (m)

M_C = Median width for crossing street (m)

If we assume that lane widths are equal to 3.5 m and parking lane widths are equal to 3 m, then the equations become as follows:

$$X_a = X_b = 0.474\ (PRSD - 1.75N_C - M_C) - 4.79$$

$$X_c = X_d = 0.474\ PRSD - 0.526(1.75N_A + M_A) - 4.71$$

Tables 19 and 20 show these distances for different speeds assuming that PRSD takes the critical value of 0.90.

For stop controlled approaches, the drivers are assumed to stop before the edge of the intersection by 10 feet. Added to this distance is the distance from the front of the vehicle to the driver which is assumed to be 8 ft, so the total distance from the

Table 19 : Minimum Distances to Obstructions on the Right of Uncontrolled Approaches

No. of Lanes of Approach Street	No. of Lanes of Crossing Street	Median Width of Crossing Street (m)	Minimum Distances to Obstructions (m) at Design Speed		
			40 Kph	50 Kph	60 Kph
2	2	0	9.3	13.3	17.3
2	2	4	7.5	11.4	15.4
2	4	0	7.7	11.6	15.6
2	4	4	5.8	9.7	13.7
4	2	0	9.3	13.3	17.3
4	2	4	7.5	11.4	15.4
4	4	4	5.8	9.7	13.7

Table 20 : Minimum Distances to Obstructions on the Right of Uncontrolled Approaches

No. of Lanes of Approach Street	No. of Lanes of Crossing Street	Median Width of Crossing Street (m)	Minimum Distances to Obstructions (m) at Design Speed		
			40 Kph	50 Kph	60 Kph
2	2	0	9.2	13.2	17.1
2	2	4	7.1	11.1	15.0
2	4	0	9.2	13.2	17.1
2	4	4	7.1	11.1	15.0
4	2	0	7.4	11.4	15.3
4	2	4	5.3	9.3	13.2
4	4	4	5.3	9.3	13.2

edge of the street to the driver is 18 ft (5.5 m). The distances X_a, X_b, X_c, and X_d can be calculated using simple trigonometry. The resulting equations are as follows:

$$X_a = X_b = \frac{6.875\ \text{CRSD} - (P_A + LW_A - 1)(P_C + LW_C \frac{N_C}{2} + M_C + 6.5)}{1.25\ \text{CRSD} + P_C + LW_C \frac{N_C}{2} + M_C + 6.5}$$

$$X_c = X_d = \frac{6.875\ \text{CRSD} - (P_C + LW_C + 4.5)(P_A + LW_A + 1)}{1.25\ \text{CRSD} + P_C + LW_C + 4.5}$$

where CRSD = Crossing sight distance in meters.

If lane widths are assumed to be 3.5 m and parking lane widths to be 3 m, then the equations are simplified to the following:

$$X_a = X_b = \frac{6.875\ \text{CRSD} - 5.5\ (9.5 + 1.75\ N_C + M_C)}{1.25\ \text{CRSD} + 9.5 + 1.75\ N_C + M_C}$$

$$X_c = X_d = \frac{6.875\ \text{CRSD} - 82.5}{1.25\ \text{CRSD} + 11}$$

Tables 21 and 22 show these distances for different speeds of the crossing street assuming that CRSD takes the critical value of 1.25.

From these four tables, it is obvious that if the minimum distances to obstructions on the left or on the right of uncontrolled approaches cannot be achieved, then speed limits should be reduced. If, however, these distances are not achieved even

Table 21 : Minimum Distances to Obstructions on the Right of Stop Controlled Approaches

No. of Lanes of Approach Street	No. of Lanes of Crossing Street	Median Width of Crossing Street (m)	Minimum Distances to Obstructions (m) at Design Speed of Crossing Street		
			40 Kph	50 Kph	60 Kph
2	2	0	4.2	4.4	4.5
2	2	4	3.9	4.1	4.3
2	4	0	3.9	4.2	4.3
2	4	4	3.6	3.9	4.1
2	6	0	3.7	3.9	4.1
2	6	4	3.4	3.7	3.9

Table 22 : Minimum Distances to Obstructions on the Left of Stop Controlled Approaches

No. of Lanes of Approach Street	No. of Lanes of Crossing Street	Minimum Distances to Obstructions (m) at Design Speed of Crossing Street		
		40 Kph	50 Kph	60 Kph
2	2	4.2	4.4	4.5
2	4	4.3	4.5	4.7
2	6	4.4	4.6	4.7

after reducing the speed to tolerable levels, then stop control should be implemented.

For stop controlled approaches, speed and number of lanes do not have strong effect on the minimum distances to obstructions on the left or on the right of the approaches. The minimum distances to obstructions should not be less than 5 m approximately.

Vehicles should not be allowed to park near the corners of the intersection. Parking should be prohibited for more than approximately twice the distances that was found in the above tables because parking within these distances will not permit the full attainment of the required sight distance.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

Following are the conclusions and recommendations derived from the study.

1. Right angled conflicts at uncontrolled approaches are positively related to 1/PRSD. This means that as PRSD increase, right angled conflicts decrease. Therefore, any obstruction close to the intersection or in the intersection should be removed to provide sufficient sight distance. The critical sight distance for these intersections is about 0.4 of full sight distance. After this value the decrease in conflicts is negligible.
2. Rear end conflicts at uncontrolled approaches increase as PRSD increase from 0 to 0.75, after that conflicts decrease. Rear end conflicts are positively related to $PRSD^4$ when PRSD is in the range between 0 and 0.75, and to $1/PRSD^2$ when PRSD is greater than 0.75. The critical range is approximately from 0.50 to 0.90 of PRSD.
3. Right angled and rear end conflicts at stop controlled approaches increase up to the critical value of CRSD, which is 1.05, and after that they decrease with increasing the value of CRSD. The functional form of the relationship is that of a normal distribution function. The critical range is

approximately from 0.75 to 1.25 of CRSD.

4. The percent reduction in right angled and rear end conflicts if critical sight distance is taken care of are around 58.1 and 51.4 for uncontrolled 3-legged approaches, 37.8 and 36.6 percent for uncontrolled 4-legged approaches, 60.8 and 73.8 percent for stop controlled approaches. The total conflict reductions that can be achieved are 56.6, 37.5, and 64.2 percent for uncontrolled T or Y intersections, uncontrolled cross intersections, and stop controlled approaches respectively.

5. The above four conclusions indicate that at least a value of 0.90 of PRSD for uncontrolled approaches and 1.25 of CRSD for stop controlled approaches should be considered for intersection design. The minimum distances to obstructions using these values are listed in Tables 19 through 22. If the distances to obstructions at uncontrolled approaches cannot be achieved, speed limits should be reduced, because they are related to sight distance criteria. If, however, these distances are not achieved even after reducing speed limits, stop control should be implemented.

6. Parking close to the intersection should not be allowed because the parking vehicles will not permit the full attainment of the required sight distances. Approximately twice the values given in Tables 19 through 22 should be considered as illegal parking area near intersections.

7. Speed was found to be affecting rear end conflicts at stop controlled approaches. Therefore speed limits should be enforced.

8. The type of intersection was only significant in the models for uncontrolled approaches and there was no difference between the conflict rates of stop controlled cross intersections and T and Y intersections. The reason for this is that vehicles at a stop controlled approach have to stop regardless of the type of the intersection. Whereas at uncontrolled approaches there might be two reasons why there will be less conflicts at T or Y intersection. First, in T or Y intersections there are less points of conflicts. Second, in T or Y intersections there is an implied right of way. The vehicles entering the intersection from the middle leg assumes that the left and right legs have the right of way and therefore slow down or even stop.

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APPENDICES

APPENDIX A

TRAFFIC CONFLICT DEFINITIONS

A.1 General definition of a traffic conflict

" A traffic conflict is a traffic event involving two or more road users , in which one user performs atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive maneuver is undertaken"(6).

An intersection traffic conflict can be described, operationally, as a traffic event involving several distinct stages(6):

1. One vehicle makes some sort of unusual, atypical, or unexpected maneuver.
2. A second vehicle is placed in jeopardy of a collision.
3. The second vehicle reacts by braking or swerving.
4. The second vehicle then continues to proceed through the intersection.

The last stage is necessary to convince the observer that the second vehicle was, indeed, responding to the offending maneuver and not to a traffic control device such as a stop sign or a signal.

A.2 Traffic conflict types

There are 12 different conflict situations that appeared to be potentially useful in pinpointing operational or safety defeciancies. These types are explained as follows(6):

1. **Left turn, same direction:** A left turn, same direction conflict situation occurs when an instigating vehicle slows to make a left turn, thus placing a following, conflicted vehicle in jeopardy of a rear-end collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-1).
2. **Right turn, same direction:** A right turn, same direction conflict situation occurs when an instigating vehicle slows to make a Right turn ,thus placing a following, conflicted vehicle in jeopardy of a rear-end collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-2).
3. **Slow vehicle, same direction:** A slow vehicie, same direction conflict situation occurs when an instigating vehicle slows while approaching or passing through an intersection, thus placing a following vehicle in jeopardy of a rear-end collision. The following vehicle brakes or swerves, then continues through the intersection (see Figure A-3).

   The reason of the vehicle slowness may or may not be evident, but it could simply be a precautionary action, or as the result of some congestion or other cause beyond the intersection.
4. **Lane change:** A lane change conflict situation occurs when an instigating vehicle changes from one lane to another, thus

placing a following, conflicted vehicle in the new lane in jeopardy of a rea-end or side-swipe collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-4).

5. **Opposing left turn:** An opposing left turn conflict situation occurs when an oncoming vehicle makes a left turn, thus placing the conflicted vehicle in jeopardy of a head-on or broadside collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-5).
6. **Right turn, cross traffic from right:** A right turn, cross traffic from right conflict situation occurs when an instigating vehicle approaching from the right makes a right turn, thus placing a following, conflicted vehicle in jeopardy of a broadside or rear-end collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-6).
7. **Left turn, cross traffic from right:** A left turn, cross traffic from right conflict situation occurs when an instigating vehicle approaching from the right makes a left turn, thus placing the conflicted vehicle in jeopardy of a broadside collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-7).
8. **Thru cross traffic from right:** A thru cross traffic from right conflict situation occurs when an instigating vehicle approaching from the right crosses in front of a conflicted

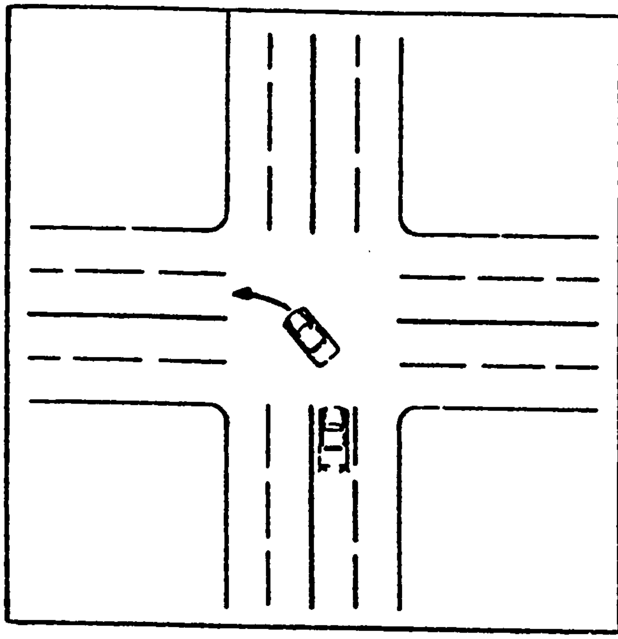

Figure A-1. Left-turn, same-direction conflict.

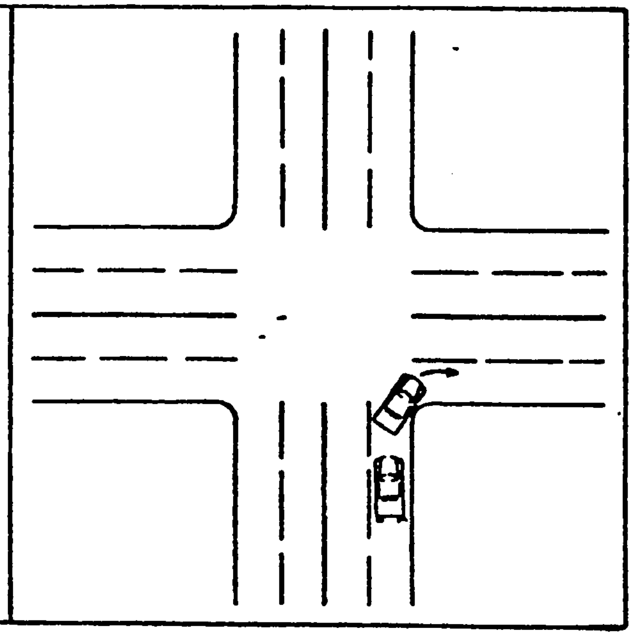

Figure A-2. Right-turn, same-direction conflict.

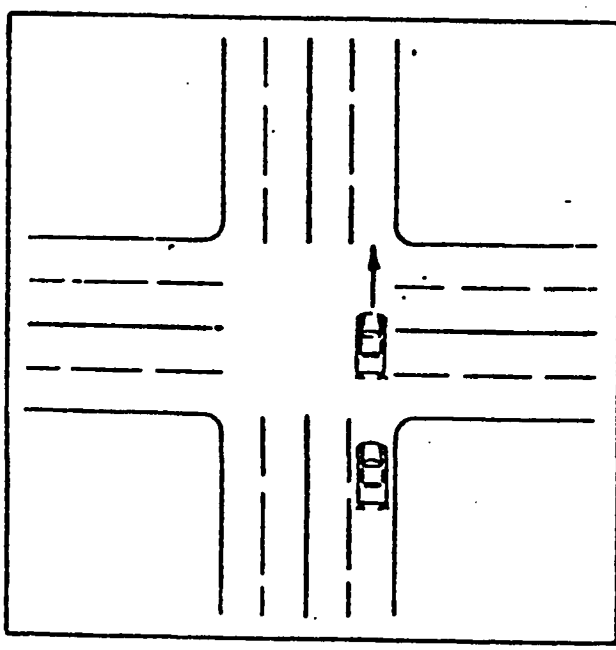

Figure A-3. Slow-vehicle, same-direction conflict.

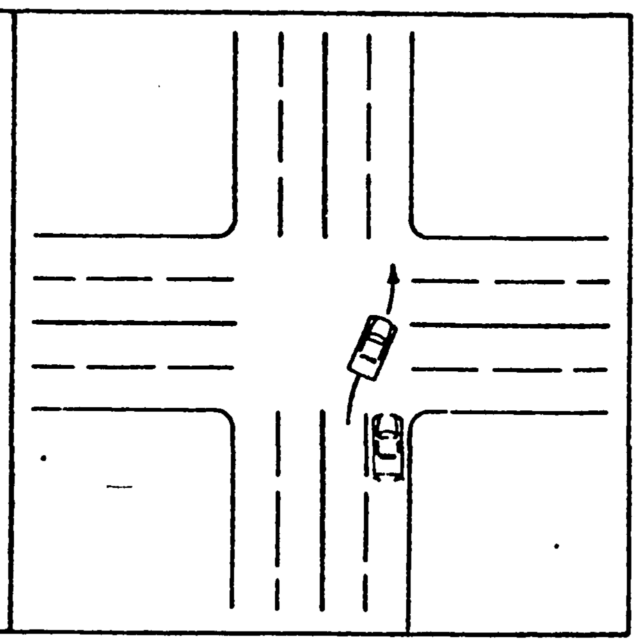

Figure A-4. Lane-change conflict.

(Source : Reference (6), p.E-13)

vehicle, thus placing it in jeopardy of a broadside collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-8).

9. **Right turn, cross traffic from left:** The right turn cross traffic from left conflict situation occurs when an instigating vehicle approaching from the left makes a right turn acroos the center of the roadway and into an opposing lane, thus placing a conflicted vehicle in that lane in jeopardy of a head-on collision. The conflicted vehicle brakes or swerves, the continues through the intersection (see Figure A-9)

10. **Left turn, cross traffic from left:** A left turn, cross traffic from left conflict situation occurs when an instigating vehicle approaching from the left makes a left turn, thus placing a conflicted vehicle in jeopardy of a broadside or rear-end collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-10).

11. **Thru cross traffic from left:** A thru cross traffic from left conflict situation occurs when an instigating vehicle approaching from the left crosses in front of a conflicted vehicle, thus placing it in jeopardy of a broadside collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure A-11).

12. **Pedestrain:** A pedestrain conflict situation occurs when a pedestrain (the instigating road user) crosses in front of a vehicle that has the right-of-way, thus creating a potential

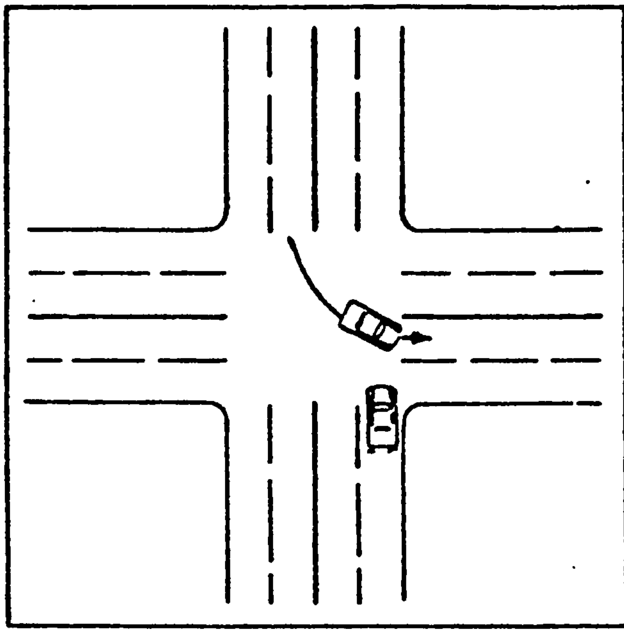

Figure A-5. Opposing left-turn conflict.

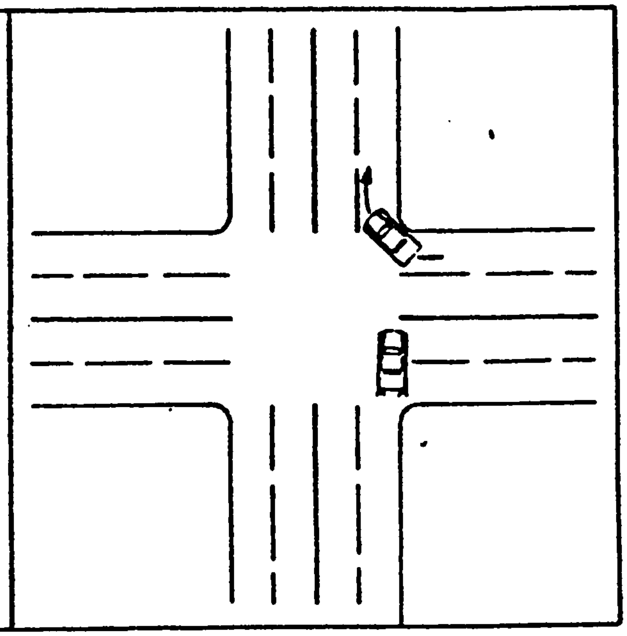

Figure A-6. Right-turn, cross-traffic-from-right conflict.

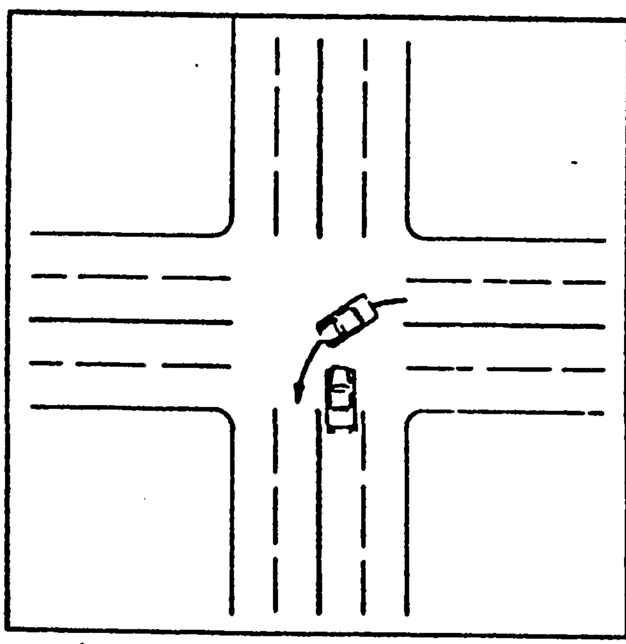

Figure A-7. Left-turn, cross-traffic-from-right conflict.

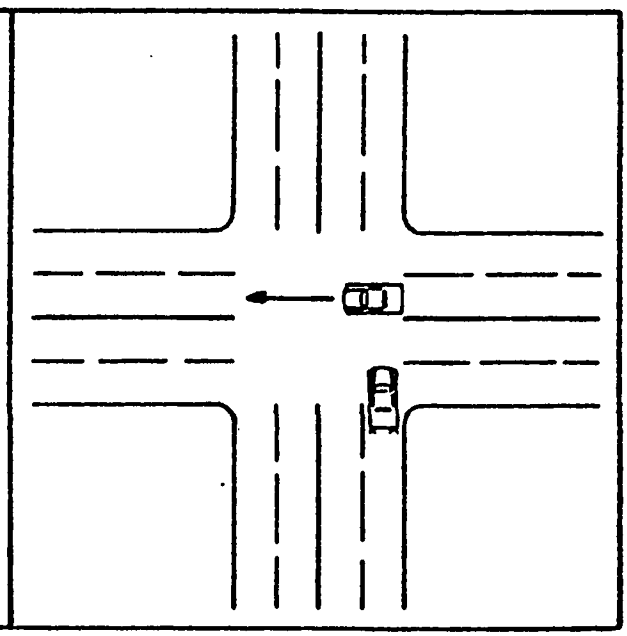

Figure A-8. Thru, cross-traffic-from-right conflict.

(Source : Reference (6), p.E-14)

collision situation. The vehicle brakes or swerves, then continues through the intersection (see Figure A-12).

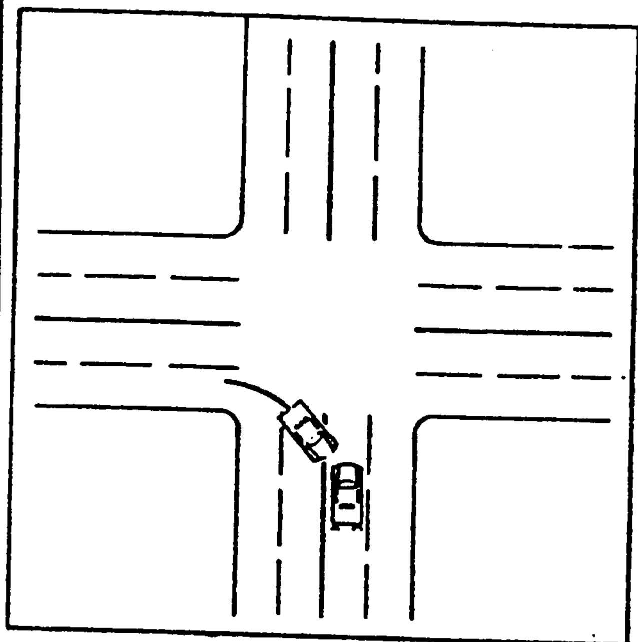

Figure A-9. Right-turn, cross-traffic-from-left conflict.

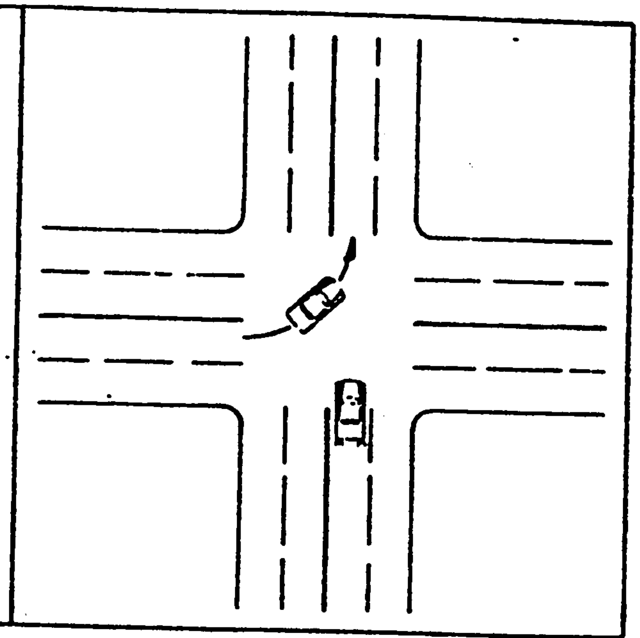

Figure A-10. Left-turn, cross-traffic-from-left conflict.

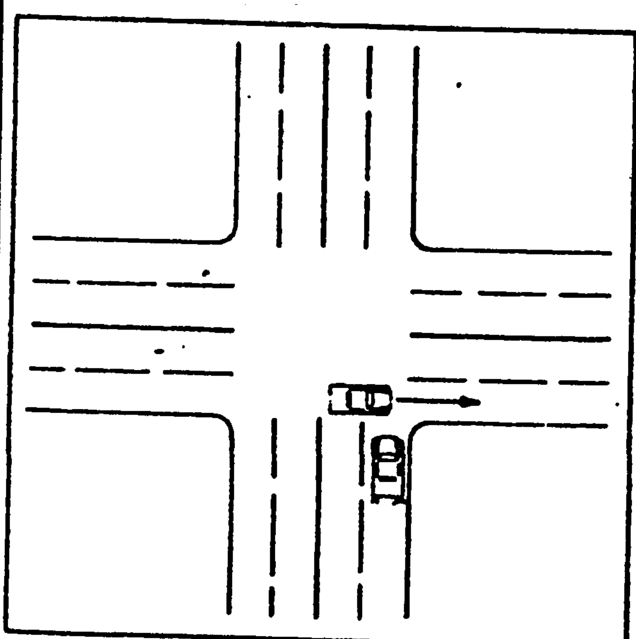

Figure A-11. Thru, cross-traffic-from-left conflict.

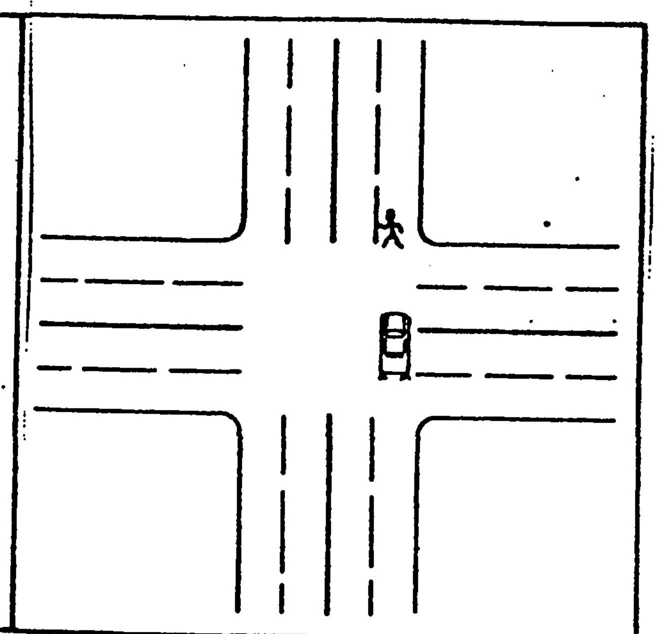

Figure A-12 Pedestrian, far-side conflict.

(Source : Reference (6), p.E-15)

APPENDIX B

DESCRIPTION OF THE SELECTED INTERSECTIONS

Table B-1 : Description of 3-legged Intersections

Inter-section	*LEG*	*Type of Control*	*No. of Lanes*	*Median*	*Left-turn Pocket*	*Lane Marking*	*Pedes trian Crossing*	*Location*
1	Left	No	1	0	0	0	0	Dammam
	Middle	No	1	0	0	0	0	
	Right	No	1	0	0	0	0	
2	Left	No	2	1	0	0	0	Thuqba
	Middle	No	2	1	0	1	0	
	Right	No	2	1	0	1	0	
3	Left	No	1	0	0	0	0	Khobar
	Middle	No	2	1	0	0	0	
	Right	No	1	0	0	0	0	
4	Left	No	2	1	0	1	0	Khobar
	Middle	No	2	1	0	0	0	
	Right	No	2	1	0	1	0	
5	Left	No	2	1	0	0	0	Dammam
	Middle	No	2	1	0	0	0	
	Right	No	2	1	0	0	0	
6	Left	No	3	1	0	0	0	Dammam
	Middle	No	3	1	0	0	0	
	Right	No	3	1	0	0	0	
7	Left	No	1	0	0	1	0	Dhahran
	Middle	No	2	0	0	0	0	
	Right	No	1	0	0	1	0	
8	Left	No	2	1	0	0	0	Dammam
	Middle	Stop	2	1	0	0	0	
	Right	No	2	1	1	0	0	
9	Left	No	3	1	0	0	0	Dammam
	Middle	Stop	3	1	0	0	0	
	Right	No	3	1	1	0	0	

Table B-1 : (Continued)

Inter-section	*LEG*	*Type of Control*	*No. of Lanes*	*Median*	*Left-turn Pocket*	*Lane Marking*	*Pedes trian Crossing*	*Location*
10	Left	No	1	1	0	1	1	Khobar
	Middle	Stop	2	0	0	1	1	
	Right	No	1	1	0	1	1	
11	Left	No	1	0	0	0	0	Agrabia
	Middle	Stop	1	0	0	0	1	
	Right	No	1	0	0	0	0	
12	Left	No	2	1	0	1	0	Khobar
	Middle	Stop	1	0	0	1	1	
	Right	No	2	1	0	1	0	
13	Left	No	3	1	0	1	0	Khobar
	Middle	Stop	1	0	0	1	1	
	Right	No	3	1	1	1	0	
14	Left	No	3	1	0	0	0	Agrabia
	Middle	Stop	1	1	0	0	0	
	Right	No	3	1	0	0	0	
15	Left	No	2	1	0	0	0	Dammam
	Middle	Stop	1	0	0	0	1	
	Right	No	2	1	0	0	0	

Table B-2 : Description of 4-legged Intersections

Intersection	*LEG*	*Type of Control*	*No. of Lanes*	*Median*	*Left-turn Pocket*	*Lane Marking*	*Pedestrian Crossing*	*Location*
1	A	No	1	0	0	0	0	Khobar
	B	No	2	1	0	1	0	
	C	No	1	0	0	0	0	
	D	No	2	1	0	1	0	
2	A	No	2	1	0	1	0	Thuqba
	B	No	1	0	0	0	0	
	C	No	2	1	0	1	0	
	D	No	1	0	0	0	0	
3	A	Red Flash	1	1	0	1	0	Khobar
	B	Yellow Flash	2	1	0	1	0	
	C	Red Flash	1	1	0	1	0	
	D	Yellow Flash	2	1	0	1	0	
4	A	No	1	1	1	1	0	Agrabia
	B	Stop	1	0	0	1	1	
	C	No	1	1	1	1	0	
	D	Stop	1	0	0	1	1	
5	A	Stop	1	0	0	1	1	Khobar
	B	No	2	1	0	0	1	
	C	Stop	1	0	0	1	1	
	D	No	2	1	0	0	1	
6	A	Stop	1	0	0	0	0	Dammam
	B	No	2	1	0	0	0	
	C	Stop	1	0	0	0	0	
	D	No	2	1	0	0	0	

APPENDIX - C

CODING MANUAL FOR INTERSECTION STUDY[1]

CARD NO.1

Column No	Codes	Description of items
1-3		Intersection number
4	1	Card Number
5		Location of Intersection
	1	Al-Aughrabia
	2	Al-Khobar
	3	Thuqba
	4	Dammam
	5	Dhahran
6		Day of Week
	1	Saturday
	2	Sunday
	3	Monday
	4	Tuesday
	5	Wednesday
	6	Thursday
7		Approach Leg No.
	1	Eastbound
	2	Northbound
	3	Westbound
	4	Southbound
8-11	--.--	Starting hour (in columns 8 and 9) in military time and minutes (in columns 10 and 11)
12-14	--.--	Approach Width (m)
15-17	--.--	Median Width (m) (put 000 if not available)
18		Median
	0	Does not Exist
	1	Exist
19		Left-turn Lane
	0	Does not Exist
	1	Exists, one lane

	2	Exists, two lanes
20		**Lane Marking**
	0	Does not exist
	1	Exists
21		**Pedestrian and/or Stop line Crossing**
	0	Does not exist
	1	Exists
22		**Curb Parking**
	0	Illegal
	1	allowed
23		**Bus Stop (near side)**
	0	Does not Exist
	1	Exists
24		**Type of Street**
	1	Arterial
	2	Collector
	3	Local
25		**Traffic Control**
	1	No control with no control at cross street
	2	No control with stop control at cross street
	3	Stop Control
	4	Yellow flashing
	5	Red flashing
	6	Signalized
		Phasing for Signalized Intersections
26-28	---	Cycle length sec (put 999 if not signalized)
29-30	--	Green time in sec (put 99 if not signalized)
31	-	Yellow time in sec (put 9 if not signalized)
		Distances from the objects obstructing the Sight Distances
32-34	--,-	a (put 998 if greater than 100 m
35-37	--,-	b and 999 if missing)
38-40	--,-	c
41-43	--,-	d
44		**Sight Distance**
	1	Bad: Less than required sight distance

	2	Good: More than required sight distance
45		**Direction**
	1	One-way approach with one way cross street
	2	One-way approach with two way cross street
	3	Two-way approach with one way cross street
	4	Two-way approach with two way cross street
46		**Leg Identifier for T Intersection**
	1	Left leg
	2	Right leg
	3	Middle leg
	9	If other than a T intersection
		Traffic Volumes
		(a) **approach Leg Volume**
47-49		Left turn volume
50-52		Through volume
53-55		Right-turn volume
		(b) **Volume of the adjacent left leg**
56-58		Left turn volume
59-61		Through volume
62-64		Right-turn volume
		(c) **Volume of Opposite Leg**
65-67		Left turn volume
68-70		Through volume
71-73		Right-turn volume
74		Number of Lanes
75-77		Lane Width in cm (if lanes are not marked, find the width after excluding the parking lane if the parking lane is marked).

CARD NUMBER 2

Column No	Codes	Description of items
1-3		Intersection Number
4	2	Card Number
		Traffic Volumes, Continued
		(d) Volume of the adjacent right leg
5-7 8-10 11-13		Left-turn Volume Through Volume. Right-turn volume
14-16	--,-	Mean Approach speed in Km./hr
17-19	--,-	Standard deviation of speed
20-23	--,-	Skewness index of speed
		TRAFFIC CONFLICTS
24-25		Left-turn same direction
26-27		Right-turn same direction
28-29		Slow-vehicle
30-31		Lane-change
32-33		Opposing left turn
34-35		Right-turn from right
36-37		Left-turn from left
38-39		Left-turn from right
40-41		Cross-traffic from left
42-43		Cross-traffic from right
44-45		Crossing on red signal
		Percent Sight Distance Available with respect to Left Approach with the Following Criteria
46-48		Perception Reaction Signt Distance

49-51	Stopping Sight Distance
52-54	Crossing Sight Distance
55-57	Turning S.D.
58-60	50-ft S.D.
	Percent Sight Distance Available with respect to Right Approach with the Following Criteria
61-63	Perception Reaction S.D.
64-66	Stopping S.D.
67-69	Crossing S.D.
70-72	Turning S.D.
73-75	50-ft S.D.
76-77	Number of Conflict Observer

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1 Al-Isa, Mohammad, G. Ergun, S. Al-Senan, A. Al-Zahrani, " Development of a Methodology for Safety Improvement at Urban Intersections", Progress Report Number 1 of KACST Research Project, November 1986.

APPENDIX D

FREQUENCY DISTRIBUTION TABLES

Table D-1 : Frequency Distribution by Intersection Type

Intersection Type	*Frequency* (%)
Cross	48 (34.8)
T/Y	90 (65.2)

Table D-2 : Frequency Distribution by Control Type

Type of Control	*Frequency* (%)
No Control with No Control On Cross Street	58 (42.0)
No Control with Stop Control On Cross Street	44 (31.9)
Stop Control	28 (20.3)
Yellow Flashing	4 (2.9)
Red Flashing	4 (2.9)

Table D-3 : Frequency Distribution by Number of Lanes

Number of Lanes	*Frequency* (%)
1	62 (44.9)
2	56 (40.6)
3	20 (14.5)

Table D-4 : Frequency Distribution by Median

Median	*Frequency* (%)
Exists	84 (60.9)
Does Not Exist	54 (39.1)

Table D-5 : Frequency Distribution by Left-turn Pocket Facility

Left-turn Pocket Facility	*Frequency* (%)
Exists One Lane	10 (7.2)
Does Not Exist	128 (92.8)

Table D-6 : Frequency Distribution by Lane Marking

Lane Marking	*Frequency* (%)
Exists	58 (42.0)
Does Not Exist	80 (58.0)

Table D-7 : Frequency Distribution by Pedestrian Crossing

Pedestrian Crossing	*Frequency* (%)
Exists	26 (18.8)
Does Not Exist	112 (81.2)

APPENDIX E

TECHNIQUES FOR DATA ANALYSIS

Following is a short explanation of the statistical techniques used in this study. More details can be found on any statistics book (22).

E-1 Multiple Regression

Multiple regression is a general statistical technique through which the relationship between a dependent or criterion variable and a set of independent or predictor variables can be analyzed. Multiple regression requires that variables are measured on interval or ratio scale. It also requires that the relationships among the variables are linear and additive. The regression model is as follows:

$$Y' = A + B_1 X_1 + B_2 X_2 + \ldots + B_k X_k$$

where Y' represents the estimated value for Y, A is the Y-intercept and B_i's are regression coefficients. The intercept and the coefficients are selected in such a way that sum of squared residuals $\Sigma (Y-Y')^2$ is minimized.

There are two tests in multiple regression to check the significance of the model as a whole and each variable separately. These tests are the F test and t test respectively.

The coefficient of correlation, R^2, is the measure of association when one is concerned with the strength of the relationship, which can be calculated using the following formula:

$$R^2 = \frac{\text{"Explained" sum of squares}}{\text{"Total" sum of squares}} = \frac{\text{Explained variance}}{\text{Total variance}}$$

R^2 ranges from a minimum of 0 to a maximum of 1.0.

E-2 Analysis of Variance (ANOVA) and Covariance

Simple analysis of variance and covariance must have a dependent or criterion variable measured on interval scale. The independent variables can be all nonmetric (categorical) variables or combination of nonmetric and metric variables. The nonmetric independent variables are called factors. The possible effects of a single factor is termed as a one-way analysis of variance. The simultaneous effects of n factors, is termed as n-way analysis of variance.

The analysis is referred to as an analysis of covariance when one is interested in analyzing the effects of both nonmetric and metric independent variables. In this analysis the metric independent variables are called covariates.

The basis of analysis of variance is the decomposition of variation or sums of squares corrected for the mean (SS). Consider a one-way analysis of variance, in which a single factor is analysed, with a dependent or criterion variable, Y, and a categorical independent variable or factor, A. The total sum of squares in Y, SS_Y, can be decomposed into two independent components:

$$SS_Y = SS_{between} + SS_{within}$$

$SS_{between}$ is the portion of the of squares in Y due to factor A, that is, due to the variation in the Y_j, means of the categories of the factor A. Thus $SS_{between}$ is denoted as SS_A. The SS_{within} is the portion of the sum of squares in Y due to the variation within each of the categories of A. Thus SS_{within} is variation which is not accounted for by factor A, and is denoted as SS_{error}. Thus,

$$SS_Y = SS_A + SS_{error}$$

The relative magnitude of SS_A will become greater as the differences among the means of Y in various categories of A (Y_j) increase and as the variation in Y within the categories of A decrease.

If there are two factors, ANOVA can test:

1. Whether the two factors as a whole have a statistically significant effect;
2. Whether the interaction effect is significant; and

3. The significance of each factor (main effects).

E-3 Multiple Classification Analysis (MCA)

Although analysis of variance (ANOVA) provides the necessary statistics for significance testing, it does not provide information about the means of the categories of the categorical variables. Also, given two or more interrelated categorical variables, one may be interested to know the net effect of each variable when the effects of other factors and covariates are controlled. Multiple Classification Analysis is used for these purposes. For example, suppose that the criterion variable is Rear End conflicts and that the factors are sight distance and intersection type and that we are interested to see the effects of these two factors. But the rear end conflicts are also affected by approach volume. Therefore the approach volume is introduced as a covariate. Then means for each category are expressed as deviation from the grand mean with and without adjustments for the covariate. Thus the net effects can be seen.

APPENDIX F

DERIVATIONS OF THE EQUATIONS OF THE MINIMUM DISTANCES TO OBSTRUCTIONS

In order to calculate the minimum distances to obstructions, two assumptions are needed for uncontrolled approaches. The first one is that the speeds of the approaches of the intersection are equal. The second assumption is that distances X_b and X_d are equal to X_a and X_c respectively, see Figure 23. For stop contorlled approaches, only the second assumption is applicable.

The minimum perception reaction sight distance for uncontrolled approaches is 0.90. The minimum crossing sight distance for stop controlled approaches is 1.25. The terms that are used here are defined in section 5.5. The steps for calculating the distances to obstructions on the right of the uncontrolled approaches are as follows (see Figure F-1):

$$a = P_C + LW_C \frac{N_C}{2} + M_C + 1$$

$$b = P_A + LW_A - 1$$

$$\frac{0.9\ PRSD - (b + x)}{a + x} = \frac{0.9\ PRSD}{PRSD}$$

$$\frac{0.9\ PRSD - (b + x)}{a + x} = 0.9$$

$$0.9\ PRSD - b - x = 0.9a + 0.9x$$

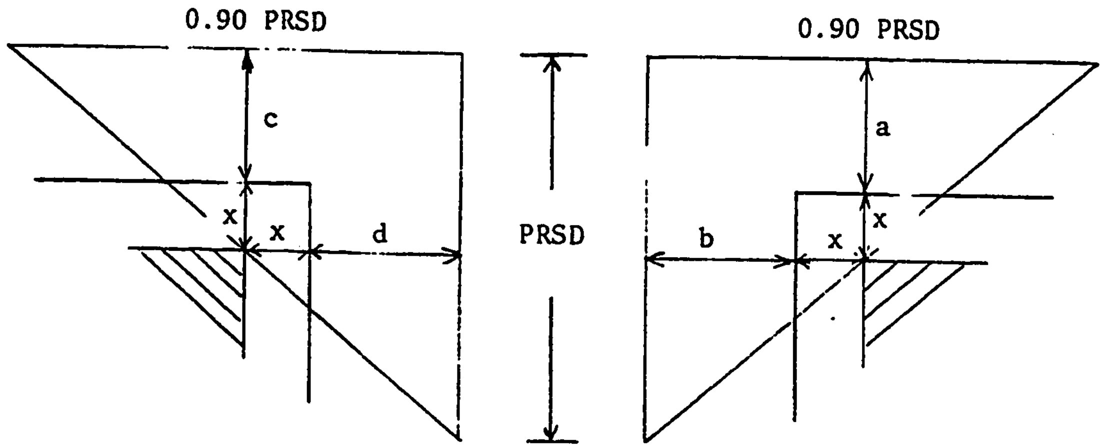

Figure F-1 : Minimum Distances to Obstructions at Uncontrolled Approaches

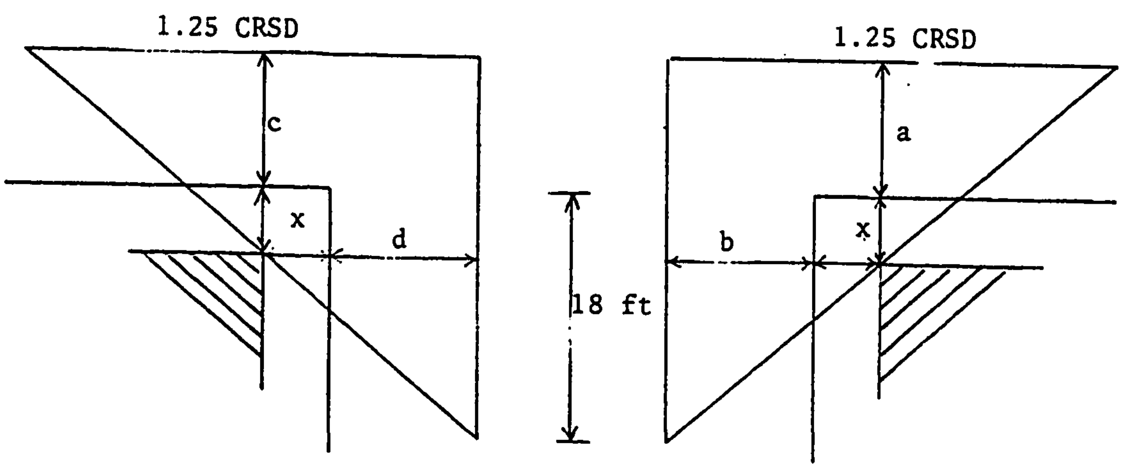

Figure F-2 : Minimum Distances to Obstructions at Stop Controlled Approaches

$$1.9x = 0.9\ PRSD - b - 0.9a$$

$$x = 0.474\ (PRSD - a) - 0.526b$$

$$X = X_a = X_b = 0.474\ (PRSD - P_C - LW_C \frac{N_C}{2} - M_C - 1) - 0.526\ (P_A + LW_A - 1)$$

The same steps can be repeated to calculate the distances to obstructions on the left of the uncontrolled approach (see Figure F-1):

$$c = P_C + LW_C - 1$$

$$d = P_A + LW_A \frac{N_A}{2} + M_A + 1$$

$$\frac{0.9\ PRSD - (x + d)}{x + c} = \frac{0.9\ PRSD}{PRSD}$$

$$\frac{0.9\ PRSD - (x + d)}{x + c} = 0.9$$

$$0.9\ PRSD - x - d = 0.9x + 0.9c$$

$$1.9x = 0.9\ (PRSD - c) - d$$

$$x = 0.474\ (PRSD - c) - 0.526d$$

$$X = X_c = X_d = 0.474\ (PRSD - P_C - LW_C + 1) - 0.526\ (P_A + LW_A \frac{N_A}{2} + M_A + 1)$$

At stop controlled approaches, the distance between the driver and edge of the crossing street is assumed to be 18 ft (5.5 m) as was explained in section 4.3. So, the distance to the obstruction on the right of the stop controlled approach can be calculated from the following steps (see Figure F-2):

$$\frac{1.25\ \text{CRSD} - (b + x)}{a + x} = \frac{1.25\ \text{CRSD}}{5.5 + a}$$

$$\frac{1.25\ \text{CRSD} - (b + x)}{1.25\ \text{CRSD}} = \frac{a + x}{5.5 + a}$$

$$\frac{1.25\ \text{CRSD}}{1.25\ \text{CRSD}} - \frac{b + x}{1.25\ \text{CRSD}} = \frac{(a + 5.5) + (x - 5.5)}{a + 5.5}$$

$$1 - \frac{b + x}{1.25\ \text{CRSD}} = 1 + \frac{x - 5.5}{a + 5.5}$$

$$-(a + 5.5)(b + x) = 1.25\ \text{CRSD}\ (x - 5.5)$$

$$-(1.25\ \text{CRSD} + a + 5.5)x = (a + 5.5)b - 5.5(1.25)\text{CRSD}$$

$$x = \frac{6.875\ \text{CRSD} - b(a + 5.5)}{1.25\ \text{CRSD} + a + 5.5}$$

$$X = X_a = X_b = \frac{6.875\ \text{CRSD} - (P_A + LW_A - 1)(P_C + LW_C \frac{N_C}{2} + M_C + 6.5)}{1.25\ \text{CRSD} + P_C + LW_C \frac{N_C}{2} + M_C + 6.5}$$

The same procedure can be used to calculate the distances to obstructions on the left of the stop controlled approach (see Figure F-2).

$$\frac{1.25\ \text{CRSD} - (x + d)}{x + c} = \frac{1.25\ \text{CRSD}}{5.5 + c}$$

Following the same steps, the result will be

$$x = \frac{6.875\ \text{CRSD} - d(c + 5.5)}{1.25\ \text{CRSD} + c + 5.5}$$

$$X = X_c = X_d = \frac{6.875\ \text{CRSD} - (P_C + LW_C + 4.5)(P_A + LW_A \frac{N_A}{2} + M_A + 1)}{1.25\ \text{CRSD} + P_C + LW_C + 4.5}$$

But in this case, N_A is equal to two and M_A is equal to zero because stopped controlled approaches usually have no medians, therefore

$$X = X_c = X_d = \frac{6.875\ \text{CRSD} - (P_C + LW_C + 4.5)(P_A + LW_A + 1)}{1.25\ \text{CRSD} + P_C + LW_C + 4.5}$$